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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 817

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. PROFESSIONAL PAPER May 12, 1920

OBSERVATIONS ON THE LIFE HISTORY OF ASCARIS LUMBRICOIDES

By

B. H. RANSOM, Chief, and W. D. FOSTER,
Junior Zoologist, Zoological Division

CONTENTS

	Page
Historical Summary	1
Probable Identity of *Ascaris lumbricoides* and *Ascaris suum*	4
Egg Stage of *Ascaris*	4
Larval Stages of *Ascaris*	10
Relation of Age to *Ascaris* Infestation	24
Ascaris Pneumonia	27
Longevity of Larvæ Outside the Host	29
Natural Occurrence of *Ascaris* in Sheep	29
Life History of Related Nematodes	30
Details of Experiments with *Ascaris*	31
General Summary	43
Bibliography	45

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By B. H. RANSOM, *Chief*, and W. D. FOSTER,[1] *Junior Zoologist, Zoological Division.*

CONTENTS.

	Page.
Historical summary	1
Probable identity of *Ascaris lumbricoides* and *Ascaris suum*	4
Egg stage of *Ascaris*	4
Incubation	4
Incubating *Ascaris* eggs for experimental use	5
Longevity of *Ascaris* eggs	6
Resistance of *Ascaris* eggs to chemical agents	6
Avenue of infection with *Ascaris*	7
Hatching of *Ascaris* eggs	8
Larval stages of *Ascaris*	10
Migrations of larvæ in body of the host	10
Development in the intestine	15
Description of larval stages	18
Larval stages of *Ascaris*—Continued.	
Relation of host to size of developing larvæ	19
Lesions associated with migrating larvæ	21
Death of migrating larvæ	23
Relation of age to *Ascaris* infestation	24
Ascaris pneumonia	27
Longevity of larvæ outside the host	29
Natural occurrence of *Ascaris* in sheep	29
Life history of related nematodes	30
Details of experiments with *Ascaris*	31
General summary	43
Bibliography	45

HISTORICAL SUMMARY.

The results of experiments by Lutz (1888), Epstein (1892), and other investigators, together with various considerations of general and special nature, have led to the acceptance of the belief to the extent that it has been taken as an established fact that *Ascaris lumbricoides* and *Ascaris suum*, parasites of man and the pig, respectively, have a direct life history and require no intermediate hosts in their cycle of development. Recent work by Stewart (1916–1918), however, has shown that the life history of *Ascaris* is not so simple as commonly supposed, and he has made the highly interesting and

[1] This paper was written after the death of Mr. Foster, which occurred October 6, 1918, but in view of his participation in the investigations upon which the paper is based his name appears as joint author.

important discovery that if a rat or a mouse is fed *Ascaris* eggs many of the larvæ which escape from the eggs in the intestine wander out of the alimentary tract, and, apparently aided by the circulation, reach the liver and later the lungs, meanwhile undergoing considerable growth and development.

Many years ago Davaine (1863) observed newly hatched larvæ in the feces of rats a few hours after feeding them *Ascaris* eggs, but Stewart was the first to discover that in these animals not all the young worms that hatched were promptly eliminated but that some penetrated the wall of the alimentary tract and reached other locations in the body, meanwhile increasing in size and undergoing certain developmental changes. He determined further that the larvæ in the lungs do not remain there, but migrate up the trachea and can be found in the mouth. On the basis of this fact Stewart (1916b) in one of his papers suggested that rats and mice that had become infected by swallowing the eggs of *Ascaris* might later transfer the parasites to human beings or pigs by contaminating food with saliva containing the young worms. Stewart, however, in continuing his investigations found that after the larvæ passed up the trachea they then passed down the esophagus, reached the intestine, and tended to accumulate in the cecum. Finally they passed out of the intestine in the feces without undergoing any material change in size or structure from that presented by the stage attained in the lungs.

Certain experiments with pigs had failed to result in definite proof that these animals became infected with *Ascaris* through swallowing the eggs, and Stewart therefore offered the hypothesis that rats and mice act as intermediate hosts in the life cycle. According to this hypothesis *Ascaris* eggs contained in the feces of infested human beings or pigs after reaching the infective stage are swallowed by rats or mice. In these hosts the young worms hatching from the eggs migrate from the intestine to the lungs and back again to the intestine and reach a stage of development considerably in advance of that characterizing the embryo within the egg. They then pass out of the body of the rat or mouse in the feces. If food contaminated with the feces of infested rats or mice is eaten by human beings or pigs the worms thus reach their final host, in whose intestine they settle down and develop to maturity. The completion of the life cycle thus requires, according to Stewart's explanation, an alternation between two hosts—the final host, man or pig, and the intermediate host, rat or mouse.

Lane (1917) and Low (1918) have given a number of reasons for doubting the validity of Stewart's explanation of the life cycle of *Ascaris*, and the present writers in a preliminary note (Ransom and

Foster, 1917) also indicated that the theory that rats and mice act as intermediate hosts is not tenable. In fact it has become quite evident that human beings and pigs become infected with *Ascaris* as a result of swallowing the eggs, the behavior of the parasites in rats and mice being simply the expression of an abortive development in animals imperfectly adapted as hosts. Our investigations have shown that the parasites migrate through the lungs in the guinea pig, rabbit, sheep, goat, pig, and presumably man, as well as in the rat and mouse. Very definite evidence has been obtained showing that the animals in which the parasites reach maturity become infected by swallowing the eggs, that the larvæ after hatching migrate out of the intestine into the lungs and back to the intestine, undergoing a development similar to that which occurs in rats, mice, and other unsuitable hosts. Having returned to the intestine, following this migration, some of the young worms may be eliminated in the feces and perish, but others may establish themselves and complete their development to the adult stage.

Stewart's very striking discoveries therefore have not upset our former views of the life history of *Ascaris* so far as concerns the spread of the parasite from infested human beings and pigs to others, but they have added some highly important facts to our former imperfect knowledge. Stewart, furthermore, has shown that the young worms not only migrate through the lungs, but in so doing may set up a serious pneumonia that in experimentally infected rats and mice is liable to be fatal. The present writers, in a preliminary note already referred to (Ransom and Foster, 1917), noted the occurrence of pneumonia in the pig as well as in smaller animals as a result of the invasion of the lungs by *Ascaris* larvæ, and Stewart in some of his later papers (1917, 1918) also reported *Ascaris* pneumonia in pigs. It is evident that *Ascaris* may likewise affect the lungs of human beings, and it is an interesting fact that Mosler (according to Leuckart, 1867) and Lutz (1888) in experiments in feeding *Ascaris* eggs to human subjects observed certain lung symptoms undoubtedly to be attributed to *Ascaris* infection, though of course the significance of the symptoms was not appreciated at the time. It is not unlikely that many cases of lung disease of obscure nature may have as an etiological factor the invasion of the lungs by *Ascaris* larvæ. Lung affections in children especially should be studied with reference to this possibility. In the case of pigs the frequent and serious condition commonly known as "thumps" is undoubtedly often the result of *Ascaris* infection. Stewart's contributions to our knowledge of the life history of *Ascaris* may accordingly prove the starting point from which an important advance can be made along the line of disease prevention.

PROBABLE IDENTITY OF ASCARIS LUMBRICOIDES AND ASCARIS SUUM.

The common intestinal roundworm of man (*Ascaris lumbricoides*) and the corresponding parasite of the pig (*A. suum* Goeze or *A. suilla* Dujardin) are morphologically indistinguishable and probably are specifically identical. Whether or not infection of man from worms harbored by the pig, and vice versa, commonly occurs is unknown and it has not yet been shown by experiment whether or not the offspring from worms harbored by one host can reach fertile maturity in the other. Although there is no good reason for considering the two forms to be distinct, in the present paper the pig *Ascaris* will be referred to as *A. suum* and the human *Ascaris* as *A. lumbricoides*, so that it may be clear in any given case whether the parasite came from a pig or from a human host.

EGG STAGE OF ASCARIS.

INCUBATION.

When deposited by the adult female in the intestine of the host animal the egg of *Ascaris* is in an early stage of segmentation. Segmentation progresses during the passage of the egg through the intestine. If the egg is not promptly eliminated in the feces of the host, however, segmentation does not continue and development of the embryo comes to a standstill. Martin (1913) found by experiments in vitro that at the body temperature of the host segmentation progresses rapidly up to a certain limit, but development of the embryo is completed only at lower temperatures. Because of the inhibiting effect of the body temperature it is necessary for the eggs to pass out of the intestine of the host before they can develop to the infective stage. Outside the body the development of the eggs is chiefly influenced by three factors—temperature, moisture, and oxygen supply. At low temperatures development proceeds slowly and may stop entirely if the temperature is low enough, so that the time required for the embryo to develop to the final stage reached in the egg may vary from a few days to many months and possibly several years.

Martin (1913) found the optimum temperature for the development of the eggs of *Ascaris vitulorum* (of the ox) and *A. suum* to be about 33° C. We have noted that a considerable proportion of the eggs of *A. suum* kept at this temperature contain fully developed embryos at the end of 10 days, and practically all complete their development within a month. In the absence of moisture, development is inhibited and extreme dryness may ultimately destroy the vitality of the eggs. The moisture requirements, however, are slight. Ross (1916) found that eggs of *A. lumbricoides* placed on glass slides and

left exposed to the sun in India for 6 weeks contained actively motile embryos at the end of that time. We have kept the eggs of *Ascaris suum* in an incubator at 37° C. until they became extremely dry, but there was no continuation of the development when the eggs were moistened and removed to a lower temperature. Though dryness may be fatal to the eggs of *Ascaris*, it is certain that under most climatic conditions there is sufficient moisture in the environment (usually the soil) into which the eggs come after elimination from the host to enable development to proceed, at least intermittently, if not continuously. The inhibiting effect of the lack of moisture and the stimulating effect of its presence may be easily observed by placing newly deposited *Ascaris* eggs in water on a slide under a cover glass, noting the stage of development and then allowing the preparation to dry naturally. In a few days, if water is added to the preparation, little or no further development will be seen to have occurred, but if the slide is kept moist for a few days it will be found that development proceeds again. By moistening or drying development may be thus favored or hindered.

As shown by Hallez (1885), oxygen is necessary to the development of *Ascaris* eggs. This is indicated by the fact that eggs in water covered by a film of oil fail to develop. We have observed that if the eggs are kept in stoppered bottles filled with water development is inhibited. According to Fauré-Fremiet (1912), the determining cause of segmentation is the oxidation of hydrocarbon reserves stored up in the egg, for which, of course, a supply of oxygen is necessary.

Bacterial decomposition of the surrounding medium inhibits development and may be destructive to the vitality of *Ascaris* eggs.

INCUBATING ASCARIS EGGS FOR EXPERIMENTAL USE.

To secure the rapid development of a high percentage of *Ascaris* eggs to the final stage for experimental purposes, various methods of incubation have been used by different investigators. Martin (1913) obtained the most satisfactory results by placing the eggs in a 2 per thousand solution of hydrochloric acid and incubating at a temperature of 33° C. Hallez (1885) spread the eggs over the surface of earth in a flowerpot which was kept moist by standing in water. After trying various methods and media we have adopted the following: The adult worms after collection are sorted by sex and size and only the larger females are retained. These are slit lengthwise and pinned out in a tray of water. The uteri are dissected out and removed. Twenty worms will furnish all the eggs that can be incubated in three petri dishes 13.5 centimeters in diameter. The uteri are snipped with scissors into as small pieces as possible and are then rubbed up with a small quantity of 2 per cent formalin in a glass mortar. This forces the eggs out of the

small sections of uterus and to some extent breaks up the clumps of eggs, so that they will spread evenly over the bottom of a petri dish. The material thus obtained is then poured into 3 petri dishes, enough 2 per cent formalin being added to fill the dishes with fluid to a depth not exceeding one-fourth of an inch. These cultures are incubated at a temperature of 33° to 34° C. To secure proper aeration of the medium it is stirred with a glass rod every 2 or 3 days. About one-third of the fertilized eggs will be found to contain motile, fully developed embryos in 10 days, and practically all will be fully developed by the end of a month.

In using the entire uterus of the worm for preparing the culture many incompletely formed eggs are introduced. This may be avoided to some extent by using only the terminal portions of the uteri, and it is preferable to do so if for any reason it is desired to keep the number of incompletely formed eggs in the culture down to a minimum. To obtain eggs for the study of their development, Wharton (1915) kept the female worms in Kronecker's solution (sodium chlorid 6 grams, caustic soda 0.06 gram, distilled water 1,000 grams), in which the worms remain alive and active from 6 to 12 days. The eggs deposited were collected each day from the bottom of the vessel in which the worms were kept.

LONGEVITY OF ASCARIS EGGS.

Ascaris eggs may remain alive for long periods. Davaine (1863) kept the embryos in eggs of *A. lumbricoides* alive for 5 years. Morris (1911) noted that in human feces which had been kept 2 years in 2 per cent formalin some of the eggs of *A. lumbricoides* present contained actively motile embryos. Two months later there was an apparent increase in the number of eggs containing active embryos. Epstein (1892) produced experimental infections with eggs of *A. lumbricoides* that had been kept in a culture of feces for a year. We have kept *Ascaris suum* eggs alive for many months and there is no reason to suppose that the length of time the eggs of the pig *Ascaris* may retain their vitality is any less than in the case of the human *Ascaris*. Because of the great longevity of the eggs it is evident that soil exposed to continual pollution with feces of infested human beings or pigs may become in course of time very heavily laden with living *Ascaris* eggs. It is also evident that places not exposed to fresh contamination may nevertheless retain their infection for years.

RESISTANCE OF ASCARIS EGGS TO CHEMICAL AGENTS.

The shells of *Ascaris* eggs are very impermeable to as well as insoluble in many chemical reagents. Formalin solutions make excellent media in which to incubate the eggs. A 10 per cent solution of potassium bichromate also makes a good culture medium. Many

observations have been made as to the slight effect upon *Ascaris* eggs of various substances that are very destructive to protoplasm. For example, Galli-Valerio (1914) succeeded in developing the eggs to a stage containing vermiform embryos in solutions of sulphuric, hydrochloric, nitric, and acetic acids 50 per cent or less in strength, in saturated solutions of copper sulphate, iron sulphate, and copper acetate, and in 50 per cent antiformin. In experiments with full-strength antiformin we have found that the shells of eggs containing motile embryos are dissolved by this substance, but the thin membranous lining of the shell remains intact. Kept in antiformin within this membrane the embryo may still be active at the end of 5 days, but if the membrane is burst by applying pressure the embryo is instantly killed by the antiformin.

We have kept *Ascaris suum* eggs containing vermiform embryos alive for several hours in carbolic acid, and embryos were still active in eggs kept 5 weeks in crude petroleum and in petrolatum. In eggs kept 10 weeks in crude petroleum no living embryos were seen, and the shells of most of the eggs were collapsed, but in most of the eggs kept the same length of time in petrolatum the embryos were active and very few eggs with collapsed shells were observed.

In view of the resistant nature and impermeability of the shell of the *Ascaris* egg it is evident that ordinary methods of disinfection by the application of chemical agents in more or less dilute solutions are of little or no use in preventing the spread of infection. According, however, to results obtained by Wigdor (1918) and unpublished results of experiments by Dr. Raffensperger and Miss Cram, phenol solutions are destructive to the eggs of *Ascaris* (or *Toxascaris* in the case of Wigdor's experiments), and it is possible that phenol disinfectants may prove useful under some conditions in the control of *Ascaris*.

AVENUE OF INFECTION WITH ASCARIS.

Infection with *Ascaris* has been shown by repeated experiment to be the result of swallowing eggs containing fully developed embryos. The possibility of natural infection in other ways than by the swallowing of eggs, however, is not absolutely excluded. Martin (1913) injected eggs of *Ascaris equorum* containing active embryos beneath the skin of a guinea pig. When the animal was killed 41 days later many empty eggshells were found at the site of injection, showing that the eggs had hatched. The fate of the embryos was not determined. Martin made similar experiments with the eggs of *A. equorum* and *A. vitulorum* on a dog, a rat, and guinea pigs, with similar results. We have repeated Martin's experiments, using eggs of *A. suum* containing active embryos (Experiment No. 13).

Our experiments show that if introduced beneath the skin *Ascaris* eggs will hatch and that within a few days the larvæ will appear in

the lungs, reaching the same stage of development as they would in a similar time if the eggs had been swallowed.

Under natural conditions there appears to be little likelihood of infection through the skin. As noted elsewhere in this article, *Ascaris* eggs sometimes hatch outside the body, but it is not known whether the newly hatched larva can penetrate the uninjured skin. The fact that the hatching of the eggs outside the body is a relatively rare occurrence indicates that infection through the skin, if it occurs at all, is likely to be very unusual. Possibly, however, eggs in contact with the skin on some parts of the body may hatch much more commonly than they do away from the body. Other possibilities can also be imagined, such as the introduction of the eggs into wounds and into the vagina.

Apart from the question of the possibility of infection through the skin, the hatching of *Ascaris* eggs when injected subcutaneously and the prompt migration of the larvæ to the lungs are of interest as demonstrating that the action of the digestive juices is unnecessary for the hatching of the eggs, and that the larvæ are probably aided by the circulation in their migration to the lungs.

HATCHING OF ASCARIS EGGS.

When *Ascaris* eggs containing fully developed embryos are swallowed they pass through the stomach unhatched; at least the great majority do. In view of the occasional hatching of *Ascaris* eggs outside the body in various media it is evidently possible that hatching in the stomach may sometimes occur. In fact, Martin (1913) observed empty eggshells and free embryos in the stomach contents of a rat and a mouse fed *Ascaris* eggs experimentally. The eggshells, however, were irregularly torn and all the embryos were dead. Martin believes that the apparently hatched eggs seen by him in the stomachs of experimental animals were eggs that had been crushed by the teeth of the animals in chewing the material with which the eggs were fed. In any event it appears quite certain that hatching in the stomach is not a normal occurrence.

Davaine (1863) fed a large number of eggs of *A. lumbricoides* containing fully developed embryos to a rat which was killed 12 hours later. In the small intestine he found unhatched eggs, eggs in the process of hatching, and free embryos. In another experiment a rat was fed large numbers of *Ascaris* eggs and numerous active embryos were afterwards observed in the feces as well as unhatched eggs, and eggs in the process of hatching. Davaine also placed *Ascaris* eggs in small glass tubes closed at the ends with gauze and fed them to a dog. These were recovered in the feces 2 days later. The eggs in early stages of segmentation were unchanged, free em-

bryos were found in the tubes, but eggs containing active embryos were no longer present. As Davaine in his experiments never found eggs hatching in the stomach, and only in the intestine, he concluded that hatching does not occur until after the eggs have passed to the small intestine. It was also shown by Davaine that some of the newly hatched larvæ may pass out of the body in the feces, and he supposed that this regularly occurs if the animal that has ingested the eggs is one in which the parasites can not attain their complete development.

By experiments in vitro Davaine (1858) found that the gastric juice of the rabbit and the dog will not digest the shell of the egg of *Ascaris lumbricoides* even when allowed to act 3 or 4 days. De Klug (1907) also observed that artificial gastric and tryptic digestion was without effect upon the shells of *Ascaris* eggs. Martin (1913) likewise found that various natural and artificial digestive juices do not dissolve the shells of *Ascaris* eggs.

From the experiments and observations of Davaine, Martin, and others it would appear that the hatching of the egg is the result of efforts on the part of the contained embryo. The shell is split and the embryo emerges through the opening, pressing apart the edges of the opening as it emerges. What factor or factors determine hatching is uncertain. Davaine (1859, 1863) reached the conclusion that the gastric juice does not act on the shell of the *Ascaris* egg and expressed the opinion that although the intestinal juices do not dissolve the shell they soften it so that the embryo, stimulated to great activity by the temperature of the body of the host, is able to break through it. Martin (1913) reaches the following conclusions:

> Hatching depends upon three factors: First, complete development of the embryo; second, a surrounding medium that is alkaline or neutral in reaction; and third, a temperature that is the same as the temperature of the host of the parasite. Digestive juices do not dissolve the eggshell. Hatching does not occur in the stomach, because of its acidity; it does occur in the intestine because of its alkalinity.

In support of his conclusions as to the factors that determine hatching, Martin has recorded the results of a considerable number of experiments in vitro with various media. The writers, in experiments on the eggs of *Ascaris suum* in vitro, have been unable to cause hatching with any regularity. We have observed that a few eggs will hatch in vitro in almost any medium, including acid as well as neutral and alkaline media, not only at the temperature of the body but at lower temperatures. The vast majority of the eggs, however, do not hatch, although the contained embryos may remain alive and active. Apparently, therefore, the factors that influence the hatching of *Ascaris* eggs are yet to be determined.

Although we are ignorant of the determining cause of hatching, nevertheless we can reach certain conclusions as to the place and manner in which hatching occurs, as follows: When *Ascaris* eggs containing fully developed embryos are swallowed they do not regularly hatch in the stomach, but pass to the small intestine, where they begin to hatch within a few hours after the eggs are swallowed. The eggshell is not dissolved by the digestive juices, the embryo being released by a split in the shell through which it emerges by its own efforts. *Ascaris* eggs may hatch not only in animals in which the parasites can develop to maturity, but apparently in almost any mammal that swallows the eggs, provided the embryos within the eggs have reached a stage in which they are ready to hatch.

LARVAL STAGES OF ASCARIS.

MIGRATIONS OF LARVÆ IN BODY OF THE HOST.

It has been stated that in artificially infected rats, mice, and other animals newly hatched *Ascaris* larvæ may be recovered in the feces within a few hours after the eggs have been swallowed. Stewart (1916–1918), however, discovered that not all the larvæ were thus eliminated, but that some migrated out of the alimentary tract into other parts of the body and soon appeared in the liver. Stewart (1916a) found larvæ in the liver of a mouse (in dilated blood capillaries) which died four days after being fed eggs of *A. lumbricoides*. In this animal the larvæ had also reached the lungs (in the air vesicles). He found larvæ of *Ascaris marginata* in the liver of mice within 24 hours after administration of the eggs, none having yet appeared in the lungs (Stewart, 1918a, p. 194). Our experiments show that the larvæ after leaving the lumen of the intestine soon appear in the liver, and may be found there before they are evident in the lungs. For example, a mouse killed 51 hours after feeding with *Ascaris suum* eggs showed numerous larvæ in the liver, but none could be found in the lungs or spleen. Frequently as late as five days after feeding *Ascaris* eggs to mice we found larvæ only in the liver, none having yet reached the lungs. In one instance, eight days after it had been fed *Ascaris suum* eggs, a mouse was killed and larvæ were found only in the liver.

The newly hatched larvæ of *Ascaris suum* measure about 0.2 to 0.3 mm. in length. In the liver the larvæ may grow to a length of 0.86 mm. (mouse nine days after infection, lungs and various other organs also infested), reaching a stage of development similar to that of larvæ of corresponding size in the lungs.

Ascaris larvæ commonly disappear from or at least become scarce in the liver within from 4 to 10 days after infection, but we have found numerous larvæ in the liver of a mouse as late as 23 days after

feeding *Ascaris suum* eggs. Apparently they leave the liver more rapidly in the case of guinea pigs and rabbits than in the case of mice, though this may be only apparent. Given the same number of larvæ in the small liver of a mouse and in the relatively large liver of a guinea pig or rabbit, the presence of larvæ in the former case might be easily detected, and in the latter only with difficulty or not at all. We have actually never seen them in the liver of a guinea pig. Most of our guinea pigs, however, were killed or died later than 4 days after feeding. Rabbits that were killed or died 8, 10, 86, and 99 days after feeding *Ascaris suum* eggs showed no larvæ in the liver. Rabbits killed 3 and 5 days after feeding showed numerous larvæ in the liver, 0.2 to 0.25 mm. long in the first case and 0.23 to 0.45 mm. long in the second.

With reference to the path of migration from the intestine to the liver and thence to the lungs, it has been pointed out (Stewart, 1917a, p. 227) that there are two apparently possible ways in which the larvæ can get from the intestine to the liver and later to the lungs. Assuming that inasmuch as the thickness of the newly hatched larva is three times the diameter of a red blood corpuscle of the mouse, it can not pass through the lumen of an ordinary capillary vessel. (1) The larva enters a mesenteric venule and is carried to the liver, where it is arrested at the entrance to the hepatic capillary plexus. Acute fatty degeneration of the liver tissue enables the larva to penetrate along the capillaries between the degenerated columns of the liver cells to the hepatic venules. The larva then passes in the hepatic vein and vena cava to the heart, and by the pulmonary artery to the lung. There it is arrested by the pulmonary capillaries. Hemorrhages of the arterioles result and the larva penetrates into the air vesicles. (2) The newly hatched larva travels up the bile duct and reaches the bile capillaries of the interlobular zone. Working its way through the degenerated liver tissue, it reaches a hepatic venule and continues its course as in the first case.

Observations made by the writers are in harmony with the suggestion that migration from the intestine to the liver may be by way of the portal system, and from the heart to the lung by the pulmonary artery. Owing to the difficulty of avoiding possible contamination with larvæ from other locations than the vessels from which the blood was taken in our experiments (Nos. 11 and 12), the results of the experiments should not be accepted as in themselves sufficient proof of the migration of the larvæ in the path indicated. From general considerations, however, Stewart's first suggestion seems more likely to be correct than the alternative suggestion. As noted elsewhere, it is quite probable that some larvæ migrate along a route different from either of those suggested by Stewart.

Stewart (1916a) found larvæ in the lungs of a mouse within 4 days after it had been fed *Ascaris lumbricoides* eggs. We have found larvæ in the lungs of the rabbit and guinea pig as early as 3 days after feeding *Ascaris suum* eggs. In rats, mice, guinea pigs, and rabbits they may be found commonly in the lungs in large numbers from 4 to 6 days after infection. As they become numerous in the lungs they disappear from or become scarce in the liver. In size the larvæ observed by us in the lungs varied in length from 0.2 or 0.3 mm. (that is, the same as the newly hatched larva), up to 1.8 mm. Larvæ of the latter length have been observed in the lungs of rabbits 10 days after infection, and slightly smaller in the lungs of a mouse 13 days after infection. There is considerable variation in the size of larvæ found in the lungs at the same time. For example, larvæ varying in length from 0.29 to 0.6 mm. were observed in the lungs of a mouse 7 days after infection; in another mouse from 0.6 to 1.12 mm. 10 days after infection; in a guinea pig from 0.3 to 0.45 mm. 4 days after infection; in another guinea pig 0.35 to 0.83 mm. 5 days after infection; in another guinea pig 0.63 to 0.93 mm. 6 days after infection; in a rabbit from 0.23 to 0.48 mm. 5 days after infection; and in another rabbit 0.9 to 1.8 mm. 10 days after infection. We have observed that living larvæ may still be found in the lungs of a mouse as late as 23 days after infection, and we have found dead larvæ encapsulated in the lungs of a rabbit killed 86 days after infection, and in the lungs of a pig we have observed degenerated larvæ 65 days after infection.

The larvæ in the lungs (Stewart, 1916a) enter the air vesicles and wander into the trachea. He found them in the bronchi as early as the seventh day and in the trachea as early as the eighth day after infection. We have found a larva in the trachea of a rabbit 3 days, and in the trachea of a guinea pig 5 days, after infection. They are often numerous in the trachea 6 days after infection. The smallest observed in the trachea was 0.23 mm. long (rabbit, 3 days after infection). In a pig 7 days after infection larvæ were observed in the trachea, varying from 0.67 to 1.33 mm.

From the trachea the larvæ enter the pharynx. We have recovered larvæ from the mouth of an experimentally infected animal.

From the pharynx the larvæ pass down the esophagus. They have been observed in the esophagus as early as 6 days after infection (guinea pig, rabbit). The latest we have observed them in the esophagus has been 10 days after infection (rabbit). No doubt they may be found still later. In a pig, 9 days after infection, we have observed larvæ in the esophagus, and there were numerous larvæ in the esophagus of a kid that died 27 days after a first feeding and 10 days after a second feeding with *Ascaris suum* eggs. In a mouse 9 days after infection the larvæ in the esophagus varied from 0.9

to 1.45 mm. in length, and in a rabbit 8 days after infection from 0.99 to 1.33 mm. in length.

Migrating *Ascaris* larvæ pass from the esophagus through the stomach into the small intestine. We have observed them in the stomach of a guinea pig 7 days, and of rabbits 8 and 10 days, after feeding with *A. suum* eggs. Numerous larvæ were present in the first and fourth stomachs of a kid that died 27 days after a first feeding and 10 days after a second feeding with *Ascaris suum* eggs. The shortest time after infection for the return of migrating *Ascaris* larvæ to the small intestine that we have observed has been 6 days. In a guinea pig a few larvæ were observed in the small intestine 6 days after *Ascaris suum* eggs had been fed. In the rabbit they have been found in the small intestine as early as 8 days, and in the mouse as early as 9 days after infection. In a mouse fed *Ascaris suum* eggs 10 days before, larvæ were found in the small intestine measuring from 0.83 to 1 mm. in length. In mice the larvæ have been observed to persist in the small intestine as late as 23 days after infection. In rats, mice, guinea pigs, and rabbits the larvæ continue their migrations down the alimentary tract and pass into the large intestine. They can be found commonly without difficulty in the cecum during a certain period. We have seen them in this location in mice as early as 9 days and as late as 23 days after infection. Those seen on the ninth day measured 0.38 to 0.46 mm. in length; larvæ measuring 0.75 to 1.45 mm. were present in the cecum of a mouse 10 days after infection. Stewart (1916c) found the larvæ in the large intestine of mice 9 to 12 days after they had been fed the eggs of *Ascaris suum*. He also found them in the feces of mice as early as 9 days and as late as 12 days after infection, and in the feces of a pig Stewart (1918b) found dead larvæ 11 days after infection. We have observed them in the feces of the mouse as late as 13 days after infection, their length ranging from 1.2 to 1.75 mm.

Summarizing the observations that have been made on the migrations of *Ascaris* larvæ in rats, mice, guinea pigs, and rabbits, it may be stated that they can be found in the liver as early as 2 days after infection, in the lungs and trachea as early as 3 days after infection, in the esophagus and small intestine as early as 6 days after infection, and in the large intestine and in the feces as early as 9 days after infection. They may still be present in the liver, lungs, and alimentary tract 23 days after infection, but, as first pointed out by Stewart, rats and mice usually become free from the parasites in a little more than 2 weeks after infection, and we have found the same to be true also of guinea pigs and rabbits.

Ascaris infestation in rats, mice, guinea pigs, and rabbits accordingly persists only 2 or 3 weeks. After the first elimination of unhatched eggs and newly hatched larvæ in the feces that takes place

during the first day or two after the eggs are swallowed, the larvæ that have migrated through the lungs begin to pass out of the body in the feces about 9 days after infection and have usually all or practically all been eliminated in less than 3 weeks after infection. During their stay in the body they may increase in size from an original length of 0.2 to 0.3 mm. to a length of nearly 2.5 mm. (Stewart), most of them, however, reaching a length not exceeding 1.75 mm., and some being not more than 1 mm. long when eliminated in the feces.

Stewart (1916a) remarked upon the occurrence of larvæ in the spleen. We have occasionally observed larvæ in the spleen, 2 being present in the spleen of a mouse examined 23 days after infection, 8 in the spleen of a mouse examined 19 days after infection, and 1 in the spleen of a mouse examined 9 days after infection—in this case measuring 0.36 mm. in length. As a rule, however, the spleens of our experimental animals, which were commonly but not always examined, showed no larvæ, so that this organ may be considered an unusual location. In one case a larva was found in the thyroid gland of a mouse 23 days after infection. In another mouse 13 days after infection larvæ were found under the peritoneum in various places in the abdominal cavity, including the Fallopian tubes. Probably the larvæ occur rather infrequently in the spleen, thyroid, and under the peritoneum of the abdominal cavity, but in our examinations, except in the case of the spleen, we rarely looked for them in these places. The kidneys have been examined repeatedly, but no larvæ have been found in them.

It has been suggested that the larvæ migrating from the intestine reach the liver by way of the portal vein, continue to the heart in the hepatic veins and vena cava, and from the heart to the lung in the pulmonary artery, and it is possible that most of the larvæ follow this course. Evidently, however, in view of their occurrence in the spleen, thyroid, etc., some of the larvæ at least may migrate along other paths. How they get to the spleen, thyroid, and under the peritoneal lining of the abdominal cavity has not been explained. The possibility is not excluded that in their migrations from the intestine some of the newly hatched larvæ are carried in the lymphatics more or less directly to the heart and reach the lungs without passing through the liver. Perhaps some of these larvæ, together with others that pass very rapidly through the liver and are soon carried in the portal circulation to the heart and lungs before they have increased much in size, get into the pulmonary veins, notwithstanding the intervening capillaries, are returned to the heart, and are then distributed to various parts of the body.

Since the foregoing was written more than a year ago, two papers by Yoshida (1919) have come to hand. In the latter of these papers Yoshida gives the results of experiments from which he concludes

that the larvæ of *Ascaris* migrate actively through the tissues to the lungs after hatching in the intestine, and he considers that the possible carriage of the larvæ in the circulation, if it does occur at all, is of secondary importance. He would also explain the presence of larvæ in the spleen, kidneys, and various other locations in which he has found them in addition to the lungs and liver, as resulting from an active penetration of the larvæ through the tissues unaided by the circulation.

DEVELOPMENT IN THE INTESTINE.

After reaching the small intestine following their migration through the lungs, *Ascaris* larvæ, if in a suitable host, settle down and develop to maturity. It appears, however, that some of them may pass on out of the intestine and perish, just as they do in the case of rats, mice, guinea pigs, and rabbits. Stewart (1918b) noted dead *Ascaris* larvæ in the feces of a pig 11 days after feeding the eggs. Accordingly, even though the host is one in which the parasites can reach maturity, not every larva that succeeds in completing the cycle through the lungs is able to establish itself in the intestine. This would seem to be the probable explanation of the fact that pigs fed the eggs of *Ascaris suum* experimentally and afterwards showing evidence of lung invasion by the larvæ, may, when killed after a lapse of time sufficient for the development of the parasites to maturity or to a stage approaching maturity in the intestine, be found to harbor only a few worms or none at all. Such failures have been noted by us. For example, a pig 27 days old was fed numerous eggs of *Ascaris suum*, October 4, 1917. Another lot of eggs was fed to this pig November 10. On November 17, or 44 days after the first feeding and 7 days after the second, the pig was killed. The liver and lungs showed numerous petechiæ similar to those occurring in other experiment animals in association with the invasion of these organs by *Ascaris* larvæ, but no larvæ were seen in the preparations examined. In the small intestine there were 8 immature *Ascaris*, 5 of which were measured and found to range from 60 to 88 mm. in length. Another pig, from the same litter, that was fed *Ascaris suum* eggs September 22, when 15 days old, died 7 days later and showed numerous larvæ in the lungs, trachea, and pharynx, those in the trachea ranging in length from 0.67 to 1.33 mm. (Experiment No. 19).

It is quite likely that the worms found in the intestine of the first pig came from the eggs fed 44 days before, but the result of the experiment by itself can not, of course, be considered conclusive proof that development of *Ascaris* in the intestines of pigs follows the ingestion of the eggs, nor that the larvæ which mature in the intestine first migrate to the lungs and back again before they settle

down in the intestines. Other possibilities are open. For example, if it is accepted that the larvæ migrate through the lungs of pigs as they do through the lungs of small experiment animals, which is shown to be the case by the result of the experiment with the second pig and other similar experiments, it is yet possible that the larvæ might be eliminated in the feces after migrating through the lungs, as in rats, mice, guinea pigs, and rabbits, and later be picked up again by the pigs and only then become established in the small intestine. Thus the mode of infection would be similar to that assumed in the theory of the rat and mouse as intermediate hosts, except that the pigs would act as their own intermediate hosts, becoming finally infected by larvæ that had once passed through their own bodies instead of through the bodies of rats or mice.

In our experiments there were also possible sources of infection other than the eggs that were fed. There may have been stray rats or mice about, or their feces may have been present in the feed, and in view of the small number of worms found in the intestine of the pig in the experiment recorded above, it may be supposed that they could have come from such a source. Owing to the difficulty of controlling experiments on pigs we have not yet succeeded in obtaining sufficient evidence from experiments on pigs alone to demonstrate conclusively that infection results from the ingestion of eggs and the subsequent migration of the larvæ through the lungs and back to the intestine, where they become established and develop to maturity. That such, however, is a fact we believe is proved by the following:

The migration of the larvæ through the lungs occurs in animals of various species that ingest the eggs irrespective of whether such animals are suitable hosts of the adult worms. This has been shown to be true of the rat, mouse, guinea pig, rabbit, goat, and pig. In man symptoms have been described by Mosler (in Leuckart, 1867) and Lutz (1888) that indicate the migration of *Ascaris* larvæ through the lungs.

The *Ascaris* embryo prior to hatching from the egg is admirably fitted to withstand the hardships of existence outside the body of a host, and may remain alive for years, protected by the eggshell. The larva after reaching the stage in which it is eliminated from unsuitable hosts, such as rats and mice, is poorly adapted to existence outside the body of a host, is quickly killed by drying, and does not long survive even under favorable conditions.

It has been shown by experiment that in lambs and kids the worms will develop to a stage approaching maturity in the intestine after infection brought about by the ingestion of the eggs of the pig *Ascaris* (Experiments Nos. 22 and 23).

In the experiments on the lamb and the kid there can be no doubt that the partially developed worms found in the intestine came from

the eggs that were fed to those animals. Obviously their infection could not reasonably be explained under the rat and mouse theory nor is it reasonable to suppose that they served as their own intermediate hosts and then swallowed their own feces containing larvæ that had been eliminated after passing through the lungs and intestine. The latter possibility, difficult to exclude in the case of pigs, is not one demanding serious consideration in the present instances, especially in view of the fact that the lamb and the kid were sucklings only a few days old when used in the experiments. Furthermore, the facts that sheep and goats are very unusual hosts of *Ascaris* and that in these experiments the parasites were found to be present in considerable numbers, in the case of the kid in enormous numbers, are facts of such a nature that the only possible conclusion is that the animals became infected from the eggs fed to them and that the larvæ after migrating from the intestine to the lungs and back again into the intestine settled down in the intestine and continued their development toward maturity. It appears, therefore, justifiable to conclude, in the light of all the available evidence, that man and pig become infected with *Ascaris* as a result of swallowing the eggs of the parasite and not from swallowing larvæ that have already undergone partial development in rats or mice.

It is evident with respect to *Ascaris suum* and probably also *Ascaris lumbricoides*, in view of the probable identity of the pig *Ascaris* and the human *Ascaris*, that these parasites show different degrees of adaptation to different host animals. In some animals (rat, mouse, guinea pig, rabbit) they are able to pass through a portion of their development and reach a stage in which they are ready to settle down in the small intestine, but are not able to develop further and are eliminated in the feces; in other animals (sheep, goat) they can develop to a stage approaching maturity, and finally, in their usual hosts (pig, man), they are able not only to pass through the earlier stages of development which may occur in imperfectly adapted hosts, but to continue their growth to fertile maturity.

The growth of *Ascaris* larvæ after they have reached the intestine following their migration through the lungs appears to be rather slow. In experiments on human subjects Epstein (1892) found that *Ascaris* eggs appeared in the feces 86 days after feeding *Ascaris lumbricoides* eggs. As the feces were also examined 12 days prior to the examination at which the eggs were first found, the worms in these cases, therefore, began producing eggs from 74 to 86 days after infection, so that at least about 2½ months were required for the full development of the parasites after infection. In our experiment with the lamb the worms were still considerably short of their adult size 103 days after infection, but, no doubt, their growth had been re-

tarded by the fact that they were in an abnormal host. We have observed full-grown *Ascaris* in a pig 11 weeks old, so that it is evident that the parasites may attain maturity in pigs within 2½ months after infection. We may therefore conclude that *Ascaris*, both in human beings and in pigs, may reach maturity as early as 2½ months after infection.

FIG. 1.—*Ascaris suum.* Egg containing fully developed embryo. Magnified 375 times.

DESCRIPTION OF LARVAL STAGES.

The newly hatched larvæ vary somewhat in size, commonly between 0.2 and 0.3 mm. in length. The specimen figured (figure 2) measured 0.22 mm. in length, 0.013 mm. in maximum thickness, esophagus 0.09 mm. in length, distance of excretory pore from anterior end of body 0.05 mm., and distance of anus from the tip of the tail 0.04 mm. The diameter of the body is nearly uniform throughout, head rounded, tail conical. On the anterior aspect of the head is a small, rounded knob, the so-called "tooth" of the *Ascaris* larva. This knob, according to Stiles (1891), is composed of three parts, corresponding to the lips of the adult *Ascaris*. In living specimens the outlines of the esophagus except posteriorly can not ordinarily be distinguished and the nerve ring is not apparent. This portion of the body is very clear, and free from color or conspicuous granules. The intestinal cells contain numerous small, yellowish-brown granules. The genital primordium is not evident in living specimens.

Before hatching, the larva (figure 1) is inclosed in a close-fitting, delicate cuticular sheath (shown in figure 2). When the larvæ are artificially expelled from the eggs (by applying pressure) they retain the sheath or in some cases cast it off as they emerge from the eggshell. At the anterior end the sheath is supplied with a crown of minute papillæ, apparently 6 in number. Under normal conditions it may be presumed that the larva undergoes its first molt at the time of hatching or shortly afterwards, following which at least another molt apparently occurs before the larva reaches the stage at which it migrates from the lungs to the intestine.

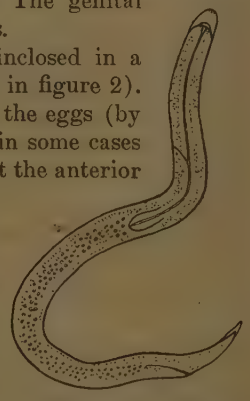

FIG. 2.—*Ascaris suum.* Newly hatched larva inclosed in cuticular sheath. Magnified 375 times.

The larvæ in the lungs reach a length of 5 to 10 times that of the newly hatched larvæ. The specimen shown (figure 3) is from the lungs of a rabbit 10 days after infection. It measures in length 1.43 mm., in maximum thickness 0.065 mm., length of esophagus 0.23 mm., distance of nerve ring from anterior end of body 0.11 mm., distance of excretory pore from

anterior end of body 0.12 mm., distance of anus from tip of tail 0.08 mm., and distance of genital primordium from tip of tail 0.48 mm. The body is of nearly uniform diameter throughout, attenuated slightly from the base of the esophagus forward, and gradually from the beginning of the posterior third of the body backward, diminishing to about half its maximum diameter in the anal region; tail conical. Along each lateral line is a well-marked membrane (shown in cross section in figure 6). The mouth is small, pharynx very short, the esophagus beginning almost immediately back of the mouth; lips not conspicuous, the knoblike process on the anterior aspect of the head characterizing the newly hatched larva being no longer present. Just in front of the bulbous posterior end of the esophagus, sometimes on the right side, sometimes on the left side, is the large nucleus of a cervical gland. The genital primordium is small, not more than 0.015 mm. in diameter, oval in shape, consisting of a very few cells, situated on the ventral side of the intestine some distance posterior of the middle of the body.

In the living worm the esophageal region is clear and transparent, the intestinal region yellowish-brown through the presence of numerous granules of this color in the intestinal cells (figure 4).

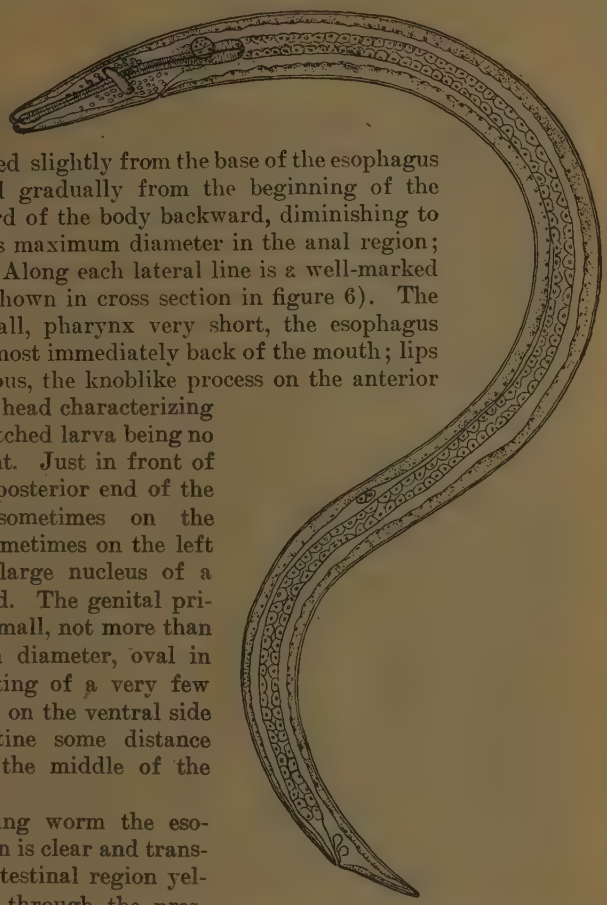

FIG. 3.—*Ascaris suum*. Larva from lung of rabbit 10 days after infection. Slightly flattened by pressure of cover glass. Magnified 150 times.

RELATION OF HOST TO SIZE OF DEVELOPING LARVÆ.

Parasites that are able to live in more than one species of host animal frequently exhibit differences of size in different species of animals. A good example is the gapeworm (*Syngamus trachealis*),

with which young chickens can readily be infected by feeding the eggs of gapeworms taken from turkeys. In turkeys full-grown gapeworms commonly reach a length of 25 to 40 mm., but in chickens infected with material from turkeys the egg-producing adult rarely exceeds 15 to 20 mm. in length.

FIG. 4. *Ascaris suum*. Larva in liver of mouse 10 days after infection. Photomicrograph of living specimen. Magnified.

In the case of migrating *Ascaris* larvæ differences of size are noticeable in different species of host animals, if a comparison is made of larvæ taken from different animals at corresponding times following infection. The following table has been compiled from the results of experiments on mice, guinea pigs, and rabbits:

Size of Ascaris larvæ in different host animals.

In mice.			In guinea pigs.			In rabbits.		
Age.	Location.	Length.	Age.	Location.	Length.	Age.	Location.	Length.
Days.		*Mm.*	*Days.*		*Mm.*	*Days.*		*Mm.*
5	Liver	0.28–0.34	4	Lungs	0.31–0.45	3	Liver	0.19–0.24
6	Lungs	.34– .4	5	do	.35– .83	5	do	.23– .45
7	do	.29– .6	5	Pharynx	.5 – .98	5	Lungs	.23– .48
9	do	.56– .86	6	Lungs	.35– .69	8	do	.33– .73
9	Large intestine.	.38– .46	6	do	.53– .9	8	Trachea	.75
10	Lungs	.6 –1.12	6	do	.63– .83	8	Esophagus	.99–1.33
10	Small intestine.	.83–1	6	Trachea	.71–1.13	8	Stomach	.6
10	Large intestine.	.75–1.45	6	Pharynx	.9	10	Lungs	.9 –1.8
			6	do	.8 –1.02	10	Stomach	1.5 –1.75
			7	Lungs	.65			

Although there is considerable variation in the size of larvæ taken from the same species of animal, from the same organ, the same number of days after infection, it is evident that there is a general increase in size with the lapse of time and with the progress of the larvæ through the liver, lungs, trachea, and into the alimentary tract; and furthermore, although differences in size between the larvæ from mice and guinea pigs, respectively, are not conspicuous, there appears to be a tendency for the larvæ to grow to a larger size in a corresponding time in rabbits than in either mice or guinea pigs. They seem to grow still larger in pigs in the same length of time. Measurements were made of 13 larvæ from the trachea of a pig that died 7 days after infection. This varied from 0.67 to 1.33 mm. in length, 8 of them being more than 1 mm. and the average close to 1.1 mm. These sizes correspond very well to those of larvæ taken from the esophagus of a rabbit 8 days after infection. The data that have been obtained as to the sizes reached by *Ascaris* larvæ in different species of host animals in a given period of time after infection are not sufficient to allow definite conclusions to be drawn, but the larvæ seem to grow more rapidly and to a larger size during their migrations in large animals than in small ones.

LESIONS ASSOCIATED WITH MIGRATING LARVÆ.

The principal organs that show pathological changes as a result of the invasion of *Ascaris* larvæ are the liver and lungs.

In the liver there is at first a capillary congestion, and hemorrhage by diapedesis; sometimes petechial or ecchymotic areas of inflammation are evident on the surface of the liver which later may become focal areas of necrosis. Commonly, however, as the larvæ leave the liver the congestion subsides. In our most severe cases, such as in the experiment (No. 23) on the kid, the inflammation was very extensive, the liver engorged with blood, bleeding freely

when cut but cutting with difficulty, indicating a beginning induration.

The lesions in the lungs are more striking macroscopically than those in the liver. In our mildest cases there were small bright-red hemorrhagic spots, in which the larvæ usually could be discovered without difficulty. As a rule the lungs were more or less edematous. The small bright-red petechial hemorrhages and edema are very characteristic of *Ascaris* invasion and differentiate it from other conditions that are likely to be seen in the lungs of pigs. In more

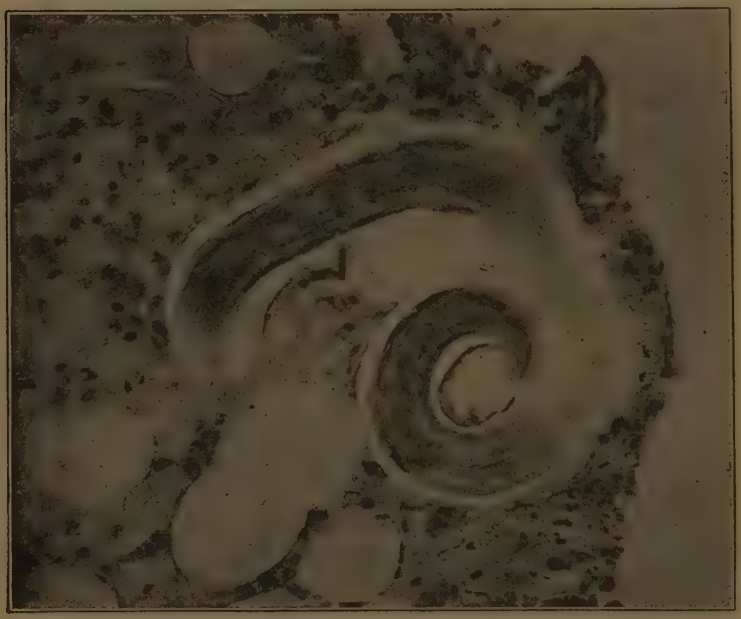

FIG. 5.—*Ascaris suum*. Larva in section of lung of mouse 1 week after infection. Photomicrograph. Highly magnified.

severe cases there were ecchymotic patches of considerable size, giving the lung a spotted appearance. In still more severe cases an entire lobe of the lung was involved, and in the worst cases both lungs were greatly swollen, edematous, intensely hemorrhagic, the color of liver, and extensively hepatized. Microscopically the pathological picture varied from that of an acute lobular pneumonia in which the areas of inflammation centered around the bronchioles to lobar pneumonia in the stage of red hepatization. The accompanying photomicrograph (figure 5) shows a section of the lung of a mouse with a larva in situ 7 days after ingestion of *Ascaris suum* eggs. In portions of the section will be noted areas of consolidation,

the air sacs being almost entirely filled in with the serosanguineous exudate. Extensive immigration of leucocytes and round-cell infiltration characteristic of acute inflammation are well marked. In other portions of the section the alveoli are enlarged, indicating a compensatory emphysema. Similar appearances are shown in figure 6, a photomicrograph of a portion of the lung of a pig one week after the ingestion of *Ascaris suum* eggs.

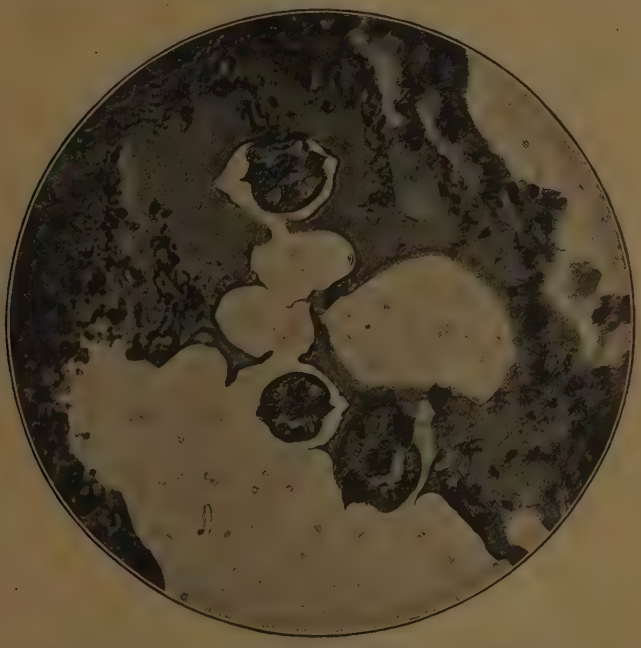

FIG. 6.—*Ascaris suum*. Larvæ in cross section in portion of lung of pig 1 week after infection. Photomicrograph. Highly magnified.

DEATH OF MIGRATING LARVÆ.

It is a general rule among animals that in species in which large numbers of young are produced the chances are slight that any given individual will reach maturity. In the case of *Ascaris*, which produces eggs in enormous numbers, there is a great loss of life among the parasites not only in the death of the eggs that do not reach a suitable host, but also in the failure of some eggs to hatch after they are swallowed, in the prompt elimination of such eggs and many newly hatched larvæ in the feces, and in the death of some of the larvæ in the course of their migrations through the body. Finally a further loss occurs in the elimination of larvæ in the feces after they have returned to the intestine following their migrations through the lungs. There is thus a great waste of life all along the

line in the development of *Ascaris* that is offset only by the abundant fertility of the parasite.

We have repeatedly made observations showing that *Ascaris* larvæ may die in the course of their migrations through the body. That larvæ die in the liver is evident from the finding of dead and degenerated larvæ in the liver of a mouse which was killed 296 days after it had been fed *Ascaris suum* eggs. There was a small encapsulated tumor near the margin of the liver, containing a caseous material and several dead and degenerated *Ascaris* larvæ. On several occasions dead and more or less degenerated larvæ have been found in the lungs, for example in a rabbit 86 days after infection and in a pig 65 days after infection. It is quite probable that the larvæ that migrate to the spleen, thyroid, and other organs outside the usual path of migration ultimately die and become encysted and absorbed or perhaps in some cases stimulate the surrounding tissues to other reactions. In this connection the observations made by Gaylord and Marsh (1914) are of interest. It was observed that dogs fed on sediment from fishponds developed a thyroid hyperplasia and that in the thyroids of such animals there were sometimes found larval nematodes (*Agamonematodum gaylordi* Ransom). It appears quite possible that these larvæ were the young of some nematode occurring in the fish, and that ingested by the dogs they underwent migrations somewhat similar to those of *Ascaris* larvæ, some of them finally coming to rest in the thyroid. The etiological relation of these nematodes to the hyperplastic growths of the thyroid observed by Gaylord and Marsh is problematic. A somewhat similar association of dead nematode larvæ and other parasites with various sorts of neoplasms has been noted by different observers. No evidence has yet been obtained that the death of migrating *Ascaris* larvæ in the tissues of the host is followed by any serious consequences.

RELATION OF AGE TO ASCARIS INFESTATION.

It is a well-known fact that among human beings children are more commonly infested with *Ascaris* than adults. This difference is perhaps most noticeable in localities where the parasite is comparatively rare. In other places, where a large percentage of the population are carriers of *Ascaris* the fact that the parasite is of more frequent occurrence among children is less striking, but nevertheless unless practically the entire population harbor the parasites there is a more or less distinctly greater frequency in infestation among the younger individuals than among the older. For example, in the Philippines, Garcia (1917) from fecal examinations of 1,603 persons of various ages found the highest percentage of infestation among persons in the first decade of life, less among those in the second and third decades, and still less among those in the fourth to seventh

decades. The average percentage was 27.8 and the per cent by ages was as follows:

Percentage of persons infested with Ascaris according to age (decade of life).

Decade of life.	Persons examined.	Infested.	Decade of life.	Persons examined.	Infested.
	Number.	*Per cent.*		*Number.*	*Per cent.*
First	98	42.9	Fourth	241	26.8
Second	355	33.5	Fifth	164	25.6
Third	615	33.5	Sixth and seventh	129	25.6

The greater frequency of *Ascaris* among children might be explained in two ways: First, their habits are such that they are more exposed to infection than older persons: second, children are more susceptible to infection than older persons. In the case of pigs there is no evident difference in the amount of exposure to infection between young and old animals except that the older pigs during their lifetime have had greater opportunities of becoming infected than younger pigs because they have lived longer, so that if equally susceptible at all ages older pigs should be more commonly and more heavily infested than younger pigs. As a matter of fact, however, there is a greater frequency of infestation among young than among old pigs, and they harbor more parasites than the older animals, so that it appears that young animals are more susceptible than older ones. The following table is based upon a post-mortem examination of the intestines of 2,583 hogs of various ages slaughtered for market at Chicago abattoirs. The examinations were made and the ages of the animals estimated by Dr. H. B. Raffensperger. Dr. Raffensperger sorted the worms found into three groups according to size, small (up to 2½ inches long), medium (slender worms between 2½ and 5 inches long), and adult (plump worms 5 inches or more long). Great care was taken in examining the contents of the intestine to obtain every worm possible, but it is quite certain that some of the small worms were overlooked, so that the figures are less accurate for the small than for the medium and adult worms.

Results of post-mortem examinations of hogs of various ages for the presence of Ascaris suum in the intestine.

Item.		Age in months—						
		1 to 2½	2½ to 5	5 to 7	7 to 12	12 to 18	18 to 48	All ages.
Hogs examined	number	55	584	363	699	626	256	2,583
Hogs infested	do	19	304	158	299	238	91	1,109
	per cent	34.5	52.1	43.6	42.8	38	35.5	[1] 41.1
Total worms found	number	82	1,936	684	1,489	1,243	541	5,975
Average worms per hog	do	1.6	3.3	1.9	2.1	2	2.1	[1] 2.1
Average worms per hog infested	do	4.5	6.4	4.3	5	5.2	6	[1] 5.2
Small worms [2]	per cent		4.2	4.2	4.2	5.6	.8	[1] 3.1
Medium worms [3]	do	97.6	49.2	33.2	35.9	39.4	31.4	[1] 47.8
Adult worms [4]	do	2.4	46.5	62.7	60	54.9	67.8	[1] 49.1

[1] Weighted average or per cent.
[2] Not more than 2½ inches long.
[3] Slender worms intermediate in size between small and adult worms.
[4] Plump worms 5 inches or more long.

From the table it appears that the highest percentage of intestinal infestation with *Ascaris* is found in pigs between the ages of 2½ and 5 months, about half of which are infested. Beyond this age the percentage of infestation gradually decreases until among old hogs over 1½ years of age only about one in three is infested.

The figures relating to the numbers of worms of different sizes found are of interest with reference to the question of the age at which pigs are most susceptible to infection. We know that about 2½ months is required for *Ascaris* to reach maturity after the eggs have been ingested. We should therefore expect few if any adult worms among the pigs of the first age class (1 to 2½ months), and this is the case, less than 3 per cent of the worms present in these young pigs being adult worms. In pigs 2½ to 5 months old on the other hand nearly one-half of the worms are mature, in pigs of the next class (5 to 7 months) nearly two-thirds of the worms are mature, then there is a slight decrease in the proportion of mature worms in the next two age groups, the proportion again increasing in pigs 1½ to 4 years old in which over two-thirds of the worms are mature.

It is not known how long an individual *Ascaris* may live, but in view of the rather large size of the worm and its slow growth to maturity it is probable that it is long-lived; quite likely it may live a year and perhaps much longer. Thus, infested pigs a year or more old may as a rule have acquired their worms while still very young, no additional infection having occurred after the first few months of life. The table, however, shows that pigs continue to be susceptible to infection as they grow older. In fact, the percentage of small worms among pigs 12 to 18 months old is higher than among the pigs of the younger groups and even among the oldest pigs (1½ to 4 years old) small worms were occasionally encountered, indicating recent infection, a considerable number (nearly one-third) of the worms present being of medium size, indicating comparatively recent infection (probably within 2½ months). The table nevertheless seems to show that pigs less than 5 months old are considerably more susceptible to infection than older pigs.

Without attempting further analysis of the figures given in the table, we may conclude that among the pigs coming to the Chicago market slightly more than half of those less than 5 months old have been found to be infested with *Ascaris*, and that among older pigs the frequency of infestation progressively decreased with age until among pigs 1½ years or more old only about one animal in three was infested. Further, the pigs less than 5 months old showed a greater average number of worms than older pigs, although as a natural result of the slow growth of the parasites they showed relatively fewer adult worms. Finally, it may be concluded that young pigs are

considerably more susceptible to infection than older pigs, but that this susceptibility, although diminishing, does not become lost with advancing age.

Whether the lessened susceptibility of pigs to *Ascaris* infection as they become older is the result of immunity following previous infections or of increased resistance to infection which comes with advancing age is perhaps not altogether certain, but it is likely that age is the determining factor rather than the establishing of an immunity in consequence of an earlier infection. If an immunity is established as a result of infection it is not immediately established, inasmuch as an experiment on a kid (Experiment No. 23) has shown that two infections may occur with an interval of 17 days between. Furthermore, natural cases have been observed in which there were adults and smaller worms in the intestine and at the same time larval worms in large numbers in the lungs. That age is sometimes an important factor in the occurrence of parasitic infection is indicated by experiments by the senior writer with gapeworms (*Syngamus trachealis*) which have shown that chickens become less susceptible to infection as they grow older, adult chickens rarely harboring the parasites. Various observers have noted in the case of other parasites that young animals are more susceptible to infection than older animals, and it is evident that age often has a great deal to do with susceptibility to invasions by parasites. On the other hand, in the case of some parasites and some species of host animals, no immunity develops with increasing age. For example, although there is a great reduction in the susceptibility of chickens to infection with the gapeworm as they become older, there is no marked difference in the susceptibility of turkeys of different ages to infection with the same parasite.

The question of the production of immunity to *Ascaris* infection as the result of earlier infections requires further investigation. Our present knowledge, however, indicates that as pigs grow older they become less susceptible to *Ascaris* infection, not because they have been immunized by earlier infections, but because with advancing age they become more resistant to infection.

ASCARIS PNEUMONIA.

As first shown by Stewart (1916a), the invasion of the lungs by *Ascaris* larvæ may cause a serious, sometimes fatal, pneumonia. Rats which had been fed *Ascaris* eggs became ill with a pneumonia four to six days afterwards and on post-mortem examination numerous *Ascaris* larvæ were found in the lungs. In later papers Stewart also notes the occurrence of pneumonia in mice and pigs following the administration of *Ascaris* eggs.

The present writers have also observed the common occurrence of pneumonia in animals that have been fed with *Ascaris* eggs, reference to which has already been made in a former paper (Ransom and Foster, 1917). The symptoms of pneumonia appear within a few days, usually about a week, after the ingestion of the eggs, and the animal may die within a day or two after the first symptoms are observed.

Among pigs very young animals seem more liable to develop serious cases of *Ascaris* pneumonia than older animals. Our worst cases among pigs have been in sucklings.

In view of the results of experiments on various animals (rat, mouse, guinea pig, rabbit, pig, goat), it seems quite probable that *Ascaris* larvæ are capable of causing pneumonia in human beings, particularly in children. Evidence that they may cause lung trouble in human beings is found in the fact that Mosler (in Leuckart, 1867) observed the occurrence of dyspnea among children to whom he had given *Ascaris* eggs a few days before. As Stewart has very properly remarked, experiments in infecting children with *Ascaris*, such as those carried out by Mosler and by Epstein (1892), are highly reprehensible. Even though Mosler and Epstein were unaware of the fact that *Ascaris* larvæ may cause a dangerous and possibly fatal affection of the lungs, their use of children as experimental animals can not be justified. Lutz (1888) has recorded the occurrence of symptoms in a young man who volunteered as a subject for experiments with *Ascaris* that were in all probability related to the invasion of the lungs by the larvæ, though the fact that the larvæ migrate through the lungs was, of course, not known to Lutz.

Lung affections, including the condition commonly known as "thumps," are of very common occurrence among young pigs, resulting in numerous deaths. These are undoubtedly often caused by *Ascaris* infection, and, in fact, numerous natural cases corresponding exactly to cases of experimental infection, have been observed by Dr. H. B. Raffensperger, of this bureau, in the course of investigations carried out by him under direction of the Zoological Division in various localities in the field. *Ascaris* is a common parasite and the soil in places occupied by pigs is liable to be heavily laden with the eggs of the parasite. There is consequently plenty of opportunity for newborn pigs to become infected. Dirt from the pigpen adheres to the skin of the sow, and the young pig in suckling swallows not only its mother's milk but also *Ascaris* eggs from the dirty teats. In addition, many eggs are likely to be picked up by the young pig in rooting about in the soil of the pigpen. It would therefore seem that greater care of the sow and the pigpen with reference to cleanliness, by reducing the chances of infection to which

young pigs are exposed, would go far toward reducing the losses from pneumonia.

LONGEVITY OF LARVÆ OUTSIDE THE HOST.

Stewart (1916a) noted that the newly hatched larvæ eliminated in the feces of rats recently fed the eggs of *Ascaris lumbricoides* might survive for three days. He found, further, that larvæ that had passed through the lungs and reached the large intestine of mice if placed in tap water were alive and active at the end of two hours, but were dead at the end of 24 hours. Larvæ from the lungs of a rabbit that died 10 days after feeding with the eggs of *Ascaris suum* have been kept alive in physiological salt solution by the writers for 13 days (Experiment No. 16).

The survival of larvæ as long as 13 days after their removal from the host would seem to offer some support to Stewart's rat and mouse theory, but the fact that they are so slightly resistant to unfavorable conditions, such as dryness, and as observed by Stewart may not live as long as 24 hours in tap water, is evidence very much against Stewart's suggestion as to the spread of *Ascaris* larvæ from rats and mice to human beings or pigs. It is known that adults removed from the intestine of their host can be kept alive for considerable periods of time. For example, Hall (1917) found that they may survive removal from their host as long as 26 days if kept in Kronecker's solution. Many species of parasitic nematodes can thus be kept alive with careful handling after removal from their host. The survival of *Ascaris* larvæ for a time if kept in physiological salt solution after they have been removed from a host animal is therefore a phenomenon not unusual among parasitic nematodes, and can not be considered as indicating the probability, under natural conditions, of the passage of the larvæ from one host to another and the resultant infection of the latter.

NATURAL OCCURRENCE OF ASCARIS IN SHEEP.

Sheep are occasionally found to be infested with *Ascaris*. Rudolphi (1819, p. 49) mentions under the name of *Ascaris ovis* a specimen in the collections of the Vienna Museum. Diesing (1851) and von Drasche (1883) give descriptions of this specimen, and the latter also describes two badly preserved specimens of *Ascaris* found in a sheep by Koebel. Copeman (1842) found 25 ascarids in a lamb. Neumann (1884) found several specimens of *Ascaris* in sheep. In the collections of the Bureau of Animal Industry are specimens of *Ascaris* collected from sheep at Brookings, S. Dak., Blairsville, Pa., and Bethesda, Md. Apparently in no case has a fully developed female *Ascaris* containing well-formed eggs been found in sheep.

The worms have always been apparently underdeveloped, which has led some to hold the opinion that the sheep ascarids which resemble *Ascaris lumbricoides* are imperfectly grown worms of this species, or of *Ascaris suum* if the pig *Ascaris* is considered distinct from the human *Ascaris*. In view of the experience of the writers in artificially infecting a lamb by feeding the eggs of the pig *Ascaris* it would appear that the common opinion as to the identity of the sheep *Ascaris* is correct. As further evidence of the ability of species of *Ascaris* to undergo at least a partial development in the intestine of a strange host may be cited the results of our experiment in feeding *Ascaris suum* eggs to a young goat, and it may also be noted that Jammes and Martin (1906) record the development of *Ascaris vitulorum* in the human intestine to a length of 8 mm. One of these writers swallowed *A. vitulorum* eggs and recovered the young worms in his feces 25 days later.

LIFE HISTORY OF RELATED NEMATODES.

The migration of the larvæ of intestinal parasites through the lungs of the host before they finally settle down in the intestine is not peculiar to *Ascaris*. It has been shown by Looss and others that the larvæ of hookworms and of *Strongyloides*, after entering the host through the skin, migrate to the lungs through the heart by way of the lymphatics and blood vessels, and then pass up the trachea and down the esophagus, finally reaching the intestine.

The senior writer has observed the larvæ of *Hæmonchus contortus* (stomach worm of ruminants) in the lung of a guinea pig killed 48 hours after it had been fed a culture of the larvæ, which indicates that they are able to migrate from the alimentary tract to the lungs and perhaps do so normally in their life cycle in their usual hosts, sheep, cattle, etc.

In view of the fact that the larvæ of forms belonging to diverse genera, *Ancylostoma*, *Strongyloides*, *Ascaris*, and, perhaps, *Hæmonchus*, regularly migrate through the lungs before establishing themselves in the intestine, it is quite likely that the phenomenon is one of common occurrence in the life cycle of parasitic nematodes. It is to be expected, certainly, that forms closely related to *Ascaris lumbricoides* will act similarly with respect to the migration of the larvæ through the lungs. Stewart (1918a, p. 194) found the larvæ of *Belascaris marginata* in the liver of mice 1 to 3 days after they had been fed eggs of this parasite. The present writers have fed the eggs of *Belascaris marginata* to rats and 5 days later have found the larvæ in the lungs. The lungs showed petechial hemorrhages similar to those observed in the lungs of animals invaded by the larvæ of *Ascaris lumbricoides* or *Ascaris suum* (Experiment No. 8).

A python that died at the National Zoological Park, Washington, D. C., was infested with a species of parasite corresponding to descriptions of *Ascaris anoura*. This nematode apparently passes through the lungs in its life cycle, inasmuch as in addition to 28 adult worms 115 to 160 mm. long, in the intestine of the python referred to, there were found in the lungs 65 young worms resembling in their structural details the adults from the intestine. These young worms varied in length from 18 to 38 mm., and if of the same species as the intestinal worms, as they appeared to be, it is evident that the larvæ of this species can develop much further in the lungs than the larvæ of *Ascaris lumbricoides*.

Considering the migration of the larvæ of *Ascaris* and other intestinal nematodes through the lungs, it might be argued from an evolutionary standpoint that parasitism of the lungs by nematodes is a more primitive condition than parasitism of the alimentary tract, and that only as the worms acquired a complete immunity to the effects of the digestive juices of the host did they move on into the stomach or intestines.

DETAILS OF EXPERIMENTS WITH ASCARIS.

The following records of the writers' experiments do not cover all the experiments that were made. A considerable number are omitted, as they add little to what is shown by those selected, so far as concerns the infection of experiment animals and the migrations of the larvæ in the body of the host. Numerous experiments have also been made relating to the hatching of *Ascaris* eggs in vitro, action of chemical reagents on the eggs, incubation of the eggs, etc., but the details of these experiments will not be given in the present bulletin.

Experiment No. 1.

January 15, 1917: Seven white mice fed with bread liberally soaked with a culture of eggs of *Ascaris suum*.

January 19, 1917: Second feeding.

January 24, 1917: Third feeding.

January 27, 1917: Killed two of the mice, 12 days after the first feeding, 8 days after the second, 3 days after the third. Post-mortem examination showed in one of the mice 21 larvæ in one-half of the lungs, 1 larva in the small intestine, and 1 larva in the liver. In the other, 56 larvæ in one-half of the lungs, 1 larva in the esophagus, 2 larvæ in the trachea, and none in the small intestine.

February 3, 1917: Two mice died, 19 days after the first feeding, 15 days after the second, 10 days after the third. One was examined and 1 larva found in the small intestine. The other mouse was not examined. Three of the mice originally included in this experiment either escaped from the cage or died and were destroyed without post-mortem examination. The feces remaining in the cage at the close of the experiment were examined for larvæ but none were found.

Experiment No. 2.

February 28, 1917: Fed 5 mice with eggs of *Ascaris suum* on bread.

March 3, 1917: Second feeding.

March 10, 1917: One mouse died with symptoms of pneumonia; no post-mortem.

March 14, 1917: Two more mice died from pneumonia, 14 days after the first feeding, 11 days after the second. The post-mortem showed a heavy invasion of the lungs in both mice. In one of the mice no larvæ were found in the liver or small intestine, 5 larvæ in the cecum; in the other, 2 larvæ in the liver, 36 in the small intestine, 4 in the cecum.

The larvæ in the lungs were of two rather distinct sizes evidently corresponding to the different dates of infection. The larger size varied from 0.53 to 0.88 mm., the smaller from 0.28 to 0.33 mm. in length.

March 23, 1917: Examined feces of remaining mice for larvæ. Negative.

March 26, 1917: Killed fourth mouse 26 days after first feeding, 23 days after second feeding. Post-mortem: Lungs, 15 larvæ 1.3 to 1.4 mm.; spleen, 2 larvæ 0.8 mm.; thyroid, 1 larva 0.7 mm.; liver, 2 larvæ 0.8, 0.9 mm.; small intestine, 1 larva 1.2 mm.; cecum, 7 larvæ 1.6–1.9 mm.

March 28, 1917: Examined feces of fifth mouse. Negative.

April 21, 1917: Killed fifth mouse. Negative.

Experiment No. 3.

April 27, 1917: Fed 6 mice at 11 a. m. *Ascaris suum* eggs on bread.

April 28, 1917: Killed 2 mice 28 hours after first placing food before them. One negative; in small intestine of the other 1 *Ascaris* egg with shell intact, in stomach 4 *Ascaris* eggs containing living embryos.

May 2, 1917: Killed third mouse 5 days after feeding. Several larvæ in liver, 0.4 to 0.55 mm. long; length of esophagus 0.1 to 0.3 mm., distance from anus to tip of tail 0.07 mm., greatest width 0.02 mm. Spleen, lungs, heart, kidney, stomach, small intestine, cecum, negative.

May 5, 1917: Killed fourth mouse 8 days after feeding. Larvæ in liver only, 0.4 mm. long.

May 10, 1917: Killed fifth mouse 13 days after feeding. Larvæ in liver, lungs, under peritoneum in various parts of abdominal cavity, in feces. Larvæ in feces were 1.2 to 1.75 mm. long. Length of esophagus 0.18 to 0.23 mm. Anus to tip of tail 0.1 mm. Larvæ in lungs 1.7 mm. long. Length of esophagus 0.24 mm. Anus to tip of tail 0.08 mm. Nerve ring 0.11 mm., excretory pore 0.14 mm. from anterior end of body. Maximum width of body 0.06 mm.

February 12, 1918: Killed sixth mouse 9½ months after feeding. Negative except for a few small black spots on the lungs, like the remains of old hemorrhages.

Experiment No. 4.

February 26, 1917: Fed 8 mice *Ascaris suum* eggs on bread.

March 2, 1917: First mouse died 4 days after feeding. Negative.

March 17, 1917: Killed second mouse 19 days after feeding. Seven larvæ in liver, 8 in spleen, none in other organs.

March 26, 1917: Killed third mouse 28 days after feeding. Negative.

April 19, 1917: Killed fourth mouse 52 days after feeding. Negative.

July 5, 1917: Killed fifth mouse 129 days after feeding. Negative.

November 10, 1917: Killed sixth mouse 257 days after feeding. Negative.

December 3, 1917: Killed seventh mouse 280 days after feeding. Negative.

December 19, 1917: Killed the last mouse 296 days after feeding. A small, encapsulated tumor, superficial, in liver near the margin contained degenerated larvæ and a waxy or caseous substance. No definite calcification.

Experiment No. 5.

June 23, 1917: Fed 12 white mice at 11 a. m. eggs of *Ascaris suum* on bread, after starving 24 hours.

June 25, 1917: Killed the first mouse 51 hours after feeding. In stomach 2 unhatched eggs; in small intestine a few unhatched eggs. Lungs and spleen negative. Liver heavily infested with larvæ 0.28 to 0.33 mm. long. In large intestine unhatched eggs containing viable embryos.

It is evident that within 51 hours large numbers of the larvæ have lodged in the liver, but apparently the lungs have not yet been invaded. It is interesting to note that a number of eggs still remain in various parts of the digestive tract and, apparently, are in the process of passing out, since they are found fairly numerous in the large intestine.

June 28, 1917: Killed second mouse 5 days after feeding. Liver heavily infested. Larvæ from the liver were kept alive in salt solution for 24 hours, but all died within 48 hours. Lungs, spleen, small and large intestines negative. Larvæ in liver measured 0.28 to 0.34 mm. in length.

June 29, 1917: Third mouse died of pneumonia 6 days after feeding. Intense congestion and hemorrhage by diapedesis. No larvæ in the liver, spleen, or intestines, but very numerous in the lungs. Larvæ in lungs measured 0.34 to 0.4 mm. in length.

June 30, 1917: Fourth and fifth mice died of pneumonia 7 days after feeding. Lungs heavily loaded with larvæ, 0.29 to 0.6 mm. in length. Other organs not examined.

July 2, 1917: Sixth mouse died from pneumonia 9 days after feeding. Lungs heavily infested with larvæ, 0.56 to 0.86 mm. in length. Liver heavily infested with larvæ, 0.56 to 0.86 mm. in length. Small intestine, 3 larvæ. Esophagus, numerous larvæ, 0.9 to 1.45 mm. in length. Spleen, 1 larva, 0.36 mm. long. Cecum, 4 larvæ, 0.38 to 0.46 mm. long.

July 3, 1917: Seventh mouse died 10 days after feeding. Lungs heavily infested; larvæ 0.6 to 1.12 mm. in length. Small intestine, numerous larvæ, 0.83 to 1 mm. in length. Large intestine, several larvæ, 0.75 to 1.45 mm. in length. Spleen negative.

Most of the larvæ remained actively motile in the tissues for 24 hours after the animal died, but all larvæ were apparently dead 48 hours after the death of the host.

July 5, 1917: Killed eighth mouse 12 days after feeding. Lungs heavily infested.

Of the 4 mice remaining 3 were lost track of and 1 was still alive June 5, 1918.

Experiment No. 6.

September 22, 1917: Fed 6 white mice with eggs of *Ascaris suum* on bread.

September 24, 1917: One mouse died 2 days after feeding. No larvæ in liver.

September 29, 1917: Second mouse died 7 days after feeding. Not examined.

October 4, 1917: Third mouse died from pneumonia 12 days after feeding. Numerous larvæ in lungs. Other organs not examined. Two mice born to one of the mice fed September 22.

October 5, 1917: Fourth mouse died 13 days after feeding. Not examined.

October 6, 1917: Two remaining mice died 14 days after feeding. Larvæ found in lungs.

October 9, 1917: The 2 mice born October 4 were examined and found free from infection.

Experiment No. 7.

November 4, 1917: A half-grown cat was fed many thousands of eggs of *Ascaris suum.*

November 12, 1917: Cat chloroformed and examined 8 days after feeding. Lungs, liver, spleen, small intestine, trachea, and pharynx examined and found negative.

Experiment No. 8.

August 21, 1916: Two rats were fed bread soaked in a culture of *Belascaris marginata* incubated for 33 days in weak formalin.

August 22, 1916: Feces of rats contained *Belascaris* eggs with unhatched motile embryos, and a few hatched dead embryos.

August 26, 1916: Killed one rat 5 days after feeding. Lung with hemorrhagic petechiæ. One active larva found. Other organs not thoroughly examined.

August 29, 1916: Killed second rat 8 days after feeding. Lungs with hemorrhagic petechiæ but a hurried examination failed to reveal worms.

Experiment No. 9.

October 11, 1917: Fed 6 guinea pigs with culture of *Ascaris suum*, each animal receiving two pipettes—about 2.4 cubic centimeters—of the culture. The animals were also allowed to eat oats over which a culture of *Ascaris* eggs had been poured.

October 16, 1917: Killed the first guinea pig 5 days after feeding. The postmortem showed numerous larvæ in the lungs, 1 larva in trachea, none in liver, spleen, esophagus, and small intestine.

October 17, 1917: Second guinea pig died 6 days after feeding. Lungs intensely hemorrhagic (color of beef liver). Larvæ very numerous in lungs; numerous in trachea. Esophagus, stomach, liver, spleen, small intestine all negative. The larvæ in the lungs varied in length from 0.35 to 0.69 mm., with esophagus 0.12 to 0.15 mm. in length. Those in the trachea were considerably larger, 0.71 to 1.13 mm. in length, 0.035 to 0.04 mm. in width, with esophagus 0.13 to 0.15 mm. long.

October 17, 1917: Third guinea pig died, 6 days after feeding. Lungs intensely hemorrhagic. Larvæ were very numerous in the lungs, numerous in the trachea, several in the pharynx, 2 in the esophagus. Liver, spleen, stomach, small intestine all negative. Large intestine not examined. The larvæ in the pharynx varied in length from 0.6 to 1.02 mm., the largest measuring 0.045 mm. in width, with esophagus 0.19 mm. long.

October 18, 1917: Fourth guinea pig died from pneumonia 7 days after feeding. Numerous larvæ in lungs, several in trachea, 2 in the stomach 0.49 and 0.78 mm. in length, both dead and degenerated, possibly from the action of the digestive juices. Small intestine, liver, thyroid, Fallopian tubes, pharynx, all negative. Esophagus not examined.

October 19, 1917: Fifth guinea pig died from pneumonia 8 days after feeding. Larvæ very numerous in lungs, numerous in trachea and pharynx, not found in esophagus, liver, thyroid, submaxillary glands, stomach, and small intestine.

October 19, 1917: Sixth guinea pig died from pneumonia 8 days after feeding. Larvæ very numerous in lungs, several in trachea and esophagus. Not found in liver, spleen, stomach, small intestine, uterus, or Fallopian tubes.

Experiment No. 10.

June 15, 1918: Fed 6 guinea pigs with eggs of *Ascaris suum* incubated since April 2.

June 19, 1918: Killed first guinea pig 4 days after feeding. Lungs intensely hemorrhagic. Numerous larvæ in lungs, also unhatched eggs. Larvæ in lungs measured 0.31 to 0.45 mm. in length. Liver, trachea, esophagus, negative. Other organs not examined. All the guinea pigs showed symptoms of pneumonia evidenced by dyspnea and abdominal breathing.

June 20, 1918: Guinea pig No. 2 died 5 days after feeding. Lungs intensely hemorrhagic, unhatched eggs in lungs. Larvæ in lungs, trachea, and pharynx. None in liver or small intestine. Other organs not examined. Measurements of larvæ in different organs as follows: Lungs, 0.35 to 0.83 mm. in length; trachea, 0.5 to 0.88 mm.; pharynx, 0.5 to 0.98 mm.

June 21, 1918: The 4 remaining guinea pigs died 6 days after feeding. Postmortem on third guinea pig showed pneumonia with red hepatization of the lungs; numerous larvæ in lungs, one in pharynx, none in trachea, liver, or spleen. Other organs not examined. Measurements of larvæ in different organs as follows: Lungs, 0.63 to 0.93 mm.; pharynx, 0.9 mm.

June 26, 1918: Fourth guinea pig examined (kept in refrigerator since death, June 21). Lungs hemorrhagic, containing numerous larvæ. Several larvæ in trachea; other organs not examined.

June 27, 1918: Fifth guinea pig examined (kept in refrigerator since death, June 21). Numerous larvæ in lungs, which were in a stage of red hepatization. Spleen and liver negative. Other organs not examined.

June 29, 1918: Sixth guinea pig examined (kept in refrigerator 8 days since death). Lungs heavily infested; several larvæ in trachea; larvæ in lungs and trachea, actively motile 8 days after death of host. Measurements of larvæ in different organs as follows: Trachea, 0.6 to 0.9 mm.; lungs, 0.53 to 0.9 mm.

The presence of unhatched eggs in the lungs of 2 of the guinea pigs may be explained by assuming that some of the eggs passed down the trachea instead of the esophagus, when the animals were being forcibly fed with a pipette. This explanation is strengthened by the fact that we have never seen unhatched eggs in the lungs of mice which were infested by being allowed to eat contaminated food without compulsion.

That *Ascaris* larvæ can live for some time after the death of the host is shown in this experiment in which larvæ in the lungs and trachea were seen to be actively motile 8 days after the host animal died. Apparently, however, no growth occurred during this period, since larvæ from the lungs of the guinea pig which was examined on the day of its death measured 0.63 to 0.93 mm. (maximum and minimum of 10 specimens), while larvæ from the lungs of the guinea pig which had been dead 8 days measured practically the same—0.53 to 0.9 mm. (9 specimens).

Experiment No. 11.

October 29, 1917: Fed 2 guinea pigs at 11 a. m. with about 3.6 cubic centimeters of a culture of eggs of *Ascaris suum* in weak formalin. Culture started September 1.

October 30, 1917: Killed 1 guinea pig at 3 p. m., 28 hours after feeding, bled from neck, catching blood in test tube. Centrifuged with an equal amount of 1 per cent sodium-citrate solution. No larvæ found.

October 31, 1917: Two days after feeding, second guinea pig etherized about 2 p. m. and when entirely anesthetized the abdomen was opened and blood drawn by a syringe directly from the portal vein, the blood being delivered into a test tube containing 5 cubic centimeters of a 5 per cent solution of acetic acid and centrifuged. The second specimen of the sediment taken for examination from the bottom of the tube contained two larvæ about 0.28 mm. long.

It appears from the experiment above that 48 hours after feeding cultures of *Ascaris* eggs, *Ascaris* larvæ may be found in the blood in sufficient numbers to be demonstrated in the portal circulation, but the results of a single experiment such as this can not be accepted as conclusive.

Experiment No. 12.

November 3, 1917: Fed 3 guinea pigs with culture of *Ascaris suum*.

November 5, 1917: Two days after feeding killed and examined blood of first guinea pig, keeping portal system and systemic system separate, using 3 per cent acetic acid, same technique as in previous experiment. Both liver and blood negative.

November 6, 1917: Three days after feeding killed and examined second guinea pig, drawing blood from pulmonary artery. One larva seen. Two larvæ in lungs; none in liver.

November 9, 1917: Third guinea pig died from pneumonia six days after feeding. Many larvæ in lungs, several in trachea, one in esophagus, one in small intestine, none in liver.

It appears from the above experiment that the larvæ after leaving the liver are carried by the systemic circulation to the heart and thence by the pulmonary artery to the lungs. In this experiment as early as three days after infection a few larvæ had already entered the lungs and as none were found in the liver it is possible that most of the larvæ were in the blood stream on the way to the lungs. The results of a single experiment such as this, however, can not be accepted as conclusive.

Experiment No. 13.

November 22, 1917: Three guinea pigs injected subcutaneously with *Ascaris suum* eggs.

November 30, 1917: Killed first guinea pig eight days after injection. Larva in lungs, 0.5 mm. long. Abscess at site of injection contains *Ascaris* eggs, the embryos dead and unhatched. Spleen, trachea, and esophagus negative; lungs with hemorrhagic spots.

December 4, 1917: Killed second guinea pig 11 days after injection. Larva in lungs, 1.5 mm. long; one anterior lobe of lung chocolate brown: a few hemorrhagic spots over the rest of the lungs. Spleen, trachea, and esophagus negative. Unhatched eggs containing vermiform embryos in abscess at site of injection.

December 4, 1917: Killed third guinea pig 11 days after injection. Lungs showing extensive inflammation and covered with dark hemorrhagic spots. Larvæ in lungs; one measured 1.3 mm. in length. Larvæ in trachea measuring 1.5 mm. Spleen and esophagus negative. Eggs in abscess under skin at site of injection. Some empty shells. Embryos in eggs dead.

The experiment of injecting *Ascaris* eggs beneath the skin was repeated, six guinea pigs being used. Similar results were obtained, the larvæ being found in each case in which the lungs were examined a week to 10 days after injection of the eggs.

Experiment No. 14.

December 3, 1917: Fed three rabbits (with pipette) heavy doses of a 2 per cent formalin culture of *Ascaris suum* eggs. Culture started October 22.

December 13, 1917: Ten days after feeding, one rabbit died. Lungs intensely hemorrhagic in the stage of red hepatization; extreme hemolysis. Blood thin and watery and would not coagulate after long standing. Thousands of larvæ throughout the lung tissue. Small pieces taken at random were always found swarming with worms. Larvæ were also numerous in the trachea, esophagus, lungs, and stomach. The small intestine, liver, and spleen were negative. Measurements of larvæ in different organs as follows: Lungs, 0.9 to 1.8 mm.; stomach, 1.45 to 1.75 mm.

February 27, 1918: Killed second rabbit 86 days after feeding. Two dead and encapsulated larvæ seen in the lungs; none in the liver, spleen, trachea, esophagus, or small intestine. Lungs showed a few petechiæ but otherwise were normal in appearance.

March 12, 1918: Third rabbit died from pneumonia (not verminous) 99 days after feeding. No larvæ seen in liver, lungs, trachea, esophagus, or spleen. Other organs not examined.

Experiment No. 15.

July 3, 1918: Fed 3 rabbits with eggs of *Ascaris suum* incubated since April 4, 1918.

July 6, 1918: Killed first rabbit 3 days after feeding. Numerous larvæ in liver, 1 in lungs, 1 in trachea. Spleen negative; other organs not examined. Parasites in liver, 0.2 to 0.25 mm. One in trachea measured 0.23 mm.

July 8, 1918: Killed second rabbit 5 days after feeding. Larvæ in liver and lungs. Spleen, trachea, and esophagus negative. Other organs not examined. Larvæ in liver (4 specimens), 0.23 to 0.45 mm. Larvæ in lung (9 specimens), 0.23 to 0.48 mm.

July 11, 1918: Third rabbit died 8 days after feeding. Liver negative, lungs heavily infested with larvæ, 1 in trachea, 3 in esophagus, 1 in small intestine, 1 in stomach. Larvæ in lungs (13 specimens), 0.33 to 0.73 mm.; trachea, 0.75 mm.; stomach, 0.6 mm.; esophagus (3 specimens), 0.99 to 1.33 mm.

Experiment No. 16.

December 3, 1917: Rabbit fed eggs of *Ascaris suum*.

December 13, 1917: Rabbit died; lungs heavily infested. The lungs were cut into small pieces, placed in artificial gastric juice in the incubator and the larvæ digested out of the tissues.

December 14, 1917: Larvæ removed from the digestive fluid and placed in normal salt solution at room temperature.

December 17, 1917: Some larvæ still alive.

December 26, 1917: Some larvæ still alive.

January 4, 1918: Next examination, all dead.

Experiment No. 17.

Several years before the present series of experiments, the junior writer attempted to infest hogs by feeding one lot with the eggs of *Ascaris suum*, a second lot with eggs of *Ascaris lumbricoides*, and reserving a third lot as check animals. The different lots were kept in separate pens on ground where no pigs had ever been before. The feces of all the pigs were previously examined for *Ascaris* eggs and found free. At the end of about three months the pigs which had been given eggs of *Ascaris lumbricoides* were found positive, those

given eggs of *A. suum* were still negative, while the check animals a few weeks later were found positive. No conclusions can therefore be drawn from the experiment.

Experiment No. 18.

The pigs used in this experiment were estimated to be between three and four months old when received, December 21, 1916, but it was nearly two months later before the first feeding with *Ascaris* eggs was given.

Precautions were taken to prevent outside infection after the experiment started and to insure that the animals were free from *Ascaris* before the experiment commenced. Of the 12 pigs used, 10 were found to be infested with *Ascaris* when purchased, and all 12 were given a dose of 2.5 mils of oil of chenopodium, with 1 ounce of castor oil. In our extensive experience with chenopodium we find that one dose is usually successful in removing all *Ascaris* present. In order to make doubly sure, however, three treatments with chenopodium were given, with intervals of five days to a week between doses, the last dose being given January 15, 1917. Four days later the feces of all the pigs were reexamined for *Ascaris* and all found negative. The animals were then taken from the pen, given a thorough scrubbing with soap and water, so as to reduce the chances of *Ascaris* eggs being carried over on the skin, and placed in clean pens with board floors, where no pigs had been before. Two of the animals died during the preliminary treatment; the remaining 10 were placed in three pens, as follows: Pen A, 2 check animals not given *Ascaris* eggs; pen B, 4 pigs given 1 feeding of *Ascaris* eggs; pen C, 4 pigs given repeated feedings of *Ascaris* eggs.

PEN B PIGS GIVEN ONE DOSE OF ASCARIS EGGS.

February 10, 1917: Pigs dosed with *Ascaris suum* eggs from cultures started December 14 and 29, 1916. Eggs from these cultures were also fed to mice, which subsequently developed verminous pneumonia.

March 4, 1917: Killed first pig 22 days after feeding *Ascaris* eggs. Five *Ascaris* in the small intestine, 4 of which measured 8.5 cm., 7 cm., 7 cm., and 6.5 cm. The fifth, apparently about the same size, was cut by the enterotome when the intestines were opened, and hence could not be measured.

March 7, 1917: Killed second pig 25 days after feeding *Ascaris* eggs. No *Ascaris* found.

March 21, 1917: Killed third pig 39 days after feeding *Ascaris* eggs. No *Ascaris* seen in small or large intestine or stomach. No larvæ found in spleen, lungs, or liver.

April 14, 1917: Killed fourth pig 63 days after feeding with *Ascaris* eggs. No *Ascaris* found.

PEN C PIGS GIVEN REPEATED DOSES OF ASCARIS EGGS.

February 24, 1917: Pigs given first dose of *Ascaris* eggs.

March 3, 1917: Second dose of *Ascaris* eggs.

March 20, 1917: Third dose of *Ascaris* eggs. Culture started February 27, 1917. This culture was subsequently fed to mice, and the resulting infestation proved the embryos were viable.

April 12, 1917: Fourth dose of *Ascaris* eggs.

April 27, 1917: Killed first pig 62 days after the first dose of *Ascaris* eggs, 15 days after the fourth dose. Two *Ascaris* in small intestine, 17 cm. and 19 cm., both the same age, to judge from their similarity in size. Liver, spleen, lungs, esophagus examined microscopically for larvæ; none found.

May 7, 1917: Fifth and last dose of *Ascaris* eggs given to the three remaining pigs.

June 4, 1917: Killed second pig 100 days since first feeding with *Ascaris* eggs, 28 days since the last feeding. No *Ascaris* found.

July 2, 1917: Killed third pig 128 days after first feeding with *Ascaris* eggs, and 56 days after the last feeding. Six female *Ascaris* were found, 23 cm., 24 cm., 25 cm., 26 cm., 26.5 cm., and 27 cm.; all in small intestine.

July 7, 1917: Killed fourth pig 133 days after the first feeding with *Ascaris* eggs, and 61 days after the last. Eleven female *Ascaris* were found, measuring 21 to 32 cm.

PEN A PIGS NOT FED ASCARIS EGGS.

July 7, 1917: Feces were again examined 167 days after the last fecal examination, when these pigs were first moved to their present quarters. The combined feces showed a few *Ascaris* eggs.

July 11, 1917: Feces of first pig examined; positive for *Ascaris*.

July 12, 1917: Feces of second pig examined; positive for *Ascaris*.

August 16, 1917: Reexamination of feces of first pig; *Ascaris* eggs present.

August 17, 1917: Reexamination of feces of second pig; *Ascaris* eggs present.

September 19, 1917: Feces of both pigs examined; *Ascaris* eggs present.

February 7, 1918: Feces of both pigs examined; both positive for *Ascaris*.

February 19, 1918: Second pig passed one large female *Ascaris* following dose of tartar emetic.

February 20, 1918: Both pigs killed. The first had 2 *Ascaris*, the second (which had passed 1 *Ascaris*) had 1 remaining.

Obviously the value of the conclusions to be derived from this experiment is weakened by the fact that the check animals were also infested, in spite of the precautions to guard against such a contingency. Considering the reliance which may be placed on a single dose of oil of chenopodium to rid hogs of *Ascaris* (as shown by Hall and Foster, 1918) and the fact that 3 such doses were given and the fecal examination following the last dose was negative, we have every reason to believe that the pigs were free from *Ascaris* when placed in the clean pen. Nevertheless, we can not be certain that the pigs were free from *Ascaris*, and they may have harbored young worms still in course of migration. There is also to be considered the possibility of the introduction of extraneous infection on the feet of the attendant or in the feed.

Considering first the experiment animals which were given but one feeding of *Ascaris* eggs, we find that only one of the four animals became infested in spite of the thousands of *Ascaris* eggs given to each pig, and this pig had but 5 worms—not a very convincing proof of the direct life cycle of the pig *Ascaris*. Furthermore, although the worms found were all about the same length, indicating that they came from the same infection, they had reached a rather large size, too large apparently for infection to have occurred only 22 days before.

Among the pigs which had received repeated doses of *Ascaris* eggs, 3 out of 4 were infested, the heaviest infestation being 11 *Ascaris*, the lightest 2 *Ascaris*. It is impossible to decide whether or not the worms found in these animals came from the eggs fed to them. Naturally, in view of the large number of eggs fed, massive infestations would have been expected. This, however, was not the case. A possible indication that the worms found actually came from the eggs fed to the pigs in pen C is that the average size of the worms from the pig killed 133 days after the first feeding and 61

days after the last is greater than that of the worms from the pig killed 62 days after the first feeding and 15 days after the last.

Experiment No. 19.

Our failure in Experiment No. 18 to infect all the animals that were fed eggs, and to get massive infestations, together with the fact that our check animals became infested, led us to repeat the experiment. About this time the finding of ascarids in the lung of a young pig, as already recorded (Ransom and Foster, 1917), and the fact that young animals have long been known to be particularly susceptible to parasitic infestation, suggested that more successful results from infection experiments might be obtained if very young pigs were used as subjects.

With the idea of obtaining animals as young as possible and to reduce the chances of prior infection it was decided to take a pregnant sow, eliminate all ascarids by treatment, place the sow in a clean pen for farrowing, and feed the little pigs with *Ascaris* eggs as soon as they could be handled. After numerous disappointments, a pregnant sow was procured, which, however, gave birth to 5 pigs before it could be examined and treated for *Ascaris*. Two weeks after the birth of the pigs (of which 2 only remained alive), the feces of the sow were examined. One *Ascaris* egg was seen in the first examination and others in a subsequent examination. There was considerable doubt after the first examination whether the single egg seen came from a contamination of the fecal sample or indicated a slight infestation. At any rate it was evident that if the sow was infested the little pigs had already had an opportunity to pick up eggs from the sow's feces, and it was therefore decided not to disturb the sow by anthelmintic treatment, but to proceed directly with the experiment on the pigs.

September 22, 1917: Dosed one of the little pigs with culture of eggs of *Ascaris suum*. Pig 15 days old when treated.

September 29, 1917: Pig died 7 days after dosing with *Ascaris* eggs.

October 1, 1917: Post-mortem of pig. *Ascaris* larvæ numerous in lungs, trachea, and pharynx. None found in liver, spleen, esophagus, small or large intestine. Larvæ from the trachea varied from 0.67 to 1.33 mm. in length, 0.03 to 0.06 mm. in width, with esophagus 0.12 to 0.21 mm. in length.

October 4, 1917: Fed second pig with 5 c. c. of a culture of eggs of *Ascaris suum*. Pig now 27 days old.

October 16, 1917: No signs of pneumonia.

November 10, 1917: Second feeding of *Ascaris* eggs.

November 17, 1917: Killed pig 44 days after the first feeding, 7 days after the second. Liver and lungs both show numerous petechiæ similar to those found in other experiment animals and associated with the invasion of these organs by *Ascaris* larvæ. However, no larvæ were seen in the preparations examined. The small intestine contained 8 immature *Ascaris*, 3 of which were accidentally cut by the enterotome. The remaining 5 measured as follows: Length, 88 mm., 78 mm., 70 mm., 65 mm., and 60 mm.; width, 1.5 mm., 1.3 mm., 1.2 mm., 1 mm., and 1 mm.

November 28, 1917: Feces of sow examined; several *Ascaris* eggs seen.

November 30, 1917: Sow killed; 7 *Ascaris* in small intestine, measuring 16 to 21 cm. long.

This experiment, like the preceding, is open to the criticism that outside sources of infection were not excluded, since the pigs for the first month of life were in intimate association with the mother which at the post-mortem was proved to have been infested. This, however, has no bearing on the findings

in regard to the first pig which died of verminous pneumonia. The heavy infestation in this case could not conceivably have resulted in any other way than from the massive dose of eggs given 7 days before. In regard to the second pig which was found infested with intestinal ascarids 44 days after the initial feeding of eggs, it is less certain that the worms came from the eggs that were fed. Yet the fact that all the worms found were of nearly the same size and, assuming that it takes about 2½ months for adults to develop in the pig, as it has been shown is necessary in the case of the human *Ascaris*, the facts that the worms were immature and of a size that might reasonably be expected after 44 days of growth, are not inconsistent with the presumption that the worms found came from the eggs that were fed to the animal.

Experiment No. 20.

Two young suckling pigs were used, one fed with eggs of *Ascaris lumbricoides* containing vermiform embryos, the other reserved as a check animal. Both pigs and the sow were transferred to a clean board pen soon after the pigs were born and the feces of the sow were frequently examined for evidences of *Ascaris* infestation. Throughout the experiment the feces were negative. Eighty-one days after the feeding with *Ascaris* eggs the pig was slaughtered but no *Ascaris* was found in the small intestine nor in any of the organs usually invaded by the larvæ. Seventeen days later the check animal was slaughtered and was also found free from *Ascaris* infestation. Some of the same culture of eggs used in this experiment was fed to guinea pigs, whose lungs became heavily infested with larvæ, so there is no question as to the viability of the eggs.

Experiment No. 21.

In this experiment 5 newborn pigs were used, date of birth, March 22, 1917. Three pigs were fed with the same culture of eggs used in Experiment No. 20, and 2 pigs were kept as checks. All 5 were kept with the sow in a recently built clean pen.

March 30, 1917: First pig received about 5 c. c. of a culture of eggs of *Ascaris lumbricoides*. Second pig received about 6 c. c. Third pig received about 4 c. c.

April 8, 1917: Pig No. 2 died 9 days after feeding. The lungs were spotted with numerous ecchymoses but not intensely hemorrhagic as in laboratory animals dying of verminous pneumonia. The spleen and thyroid were negative. One larva was found in the liver, the lungs were heavily infested, larvæ were numerous in the trachea, while one larva was found in the pharynx and one in the esophagus. Larvæ in the trachea varied from 0.85 to 1.04 mm. in length, with esophagus from 0.09 to 0.13 mm. long.

May 6, 1917: Sow removed from the pen. While with the pigs four fecal examinations were made at intervals, all of which proved negative.

June 3, 1917: First pig slaughtered and examined 65 days after feeding. Lungs showed lesions of broncho-pneumonia. There were 2 large hemorrhagic areas in which 2 degenerated *Ascaris* larvæ were seen. Trachea, esophagus, stomach, intestines, spleen, and liver were negative for *Ascaris*.

July 5, 1917: The third pig was slaughtered 97 days after feeding. Lungs, bronchi, trachea, esophagus, small and large intestines were all examined, but no *Ascaris* found.

July 17, 1917: Fourth pig (check animal) slaughtered and examined 109 days after feeding pigs 1, 2, and 3. Negative for *Ascaris*.

July 26, 1917: Fifth pig (second check animal) slaughtered and examined 118 days after feeding pigs 1, 2, and 3. Negative for *Ascaris*.

It might appear from these experiments that *Ascaris lumbricoides* can not develop beyond the lung stage in pigs, and that therefore there is a biological if not a morphological difference between the *Ascaris* of man and that of pigs, the *Ascaris* of man not being able to develop in the pig. Of 4 pigs fed very large doses of eggs only 2 showed any infestation, and in neither of these did the worms develop beyond the lung stage. It is true that 1 of the 4 pigs died when the parasites were actively migrating out of the lungs, and in this case the death of the host certainly interfered with further development of the larvæ, but of the 3 remaining pigs, all of which received large numbers of eggs, only one showed any infestation, and apparently in this case the larvæ that succeeded in reaching the lungs never developed further.

It is, however, hard to believe that the digestive apparatus of the pig is so different from that of man that an *Ascaris* morphologically indistinguishable from the form found in man would be unable to develop at least to an immature stage in the intestine of swine. As shown in another experiment *Ascaris suum* may develop in lambs to immature worms of considerable size, and it may also be noted that Jammes and Martin (1906) succeeded in rearing *Ascaris vitulorum* to a considerable size in a man to whom the eggs of the parasite had been administered. Yet the difference between the digestive apparatus of sheep and swine is certainly greater than that between swine and man, and undoubtedly the *Ascaris vitulorum* of calves is a distinct species from *Ascaris lumbricoides* of man. The failure to obtain at least immature worms if not mature worms in the intestines of pigs following the feeding of eggs of *A. lumbricoides* can therefore scarcely be explained upon the basis of a biological difference between the *Ascaris* of man and that of the pig.

Experiment No. 22.

March 2, 1918: Fed a 2-day-old lamb with about 3 cubic centimeters of a culture of *Ascaris suum* eggs which had been prepared January 9.

June 13, 1918: Lamb killed 103 days after feeding. Apices of lungs consolidated. No *Ascaris* larvæ found in the lungs. Duodenum showed numerous ecchymotic spots and 50 half-grown *Ascaris*, 12 males, 38 females. Males were 60–110 mm. long, average 88 mm.; females 60–132 mm. long, average 91 mm. Three worms were over 130 mm. long. Most of the specimens were between 75 and 110 mm.

Experiment No. 23.

July 3, 1918: Fed a 4-day-old kid with a large dose of eggs of *Ascaris suum* incubated since April 4, 1918. The kid showed no ill effects from this dose.

July 20, 1918: Second feeding with *Ascaris suum* eggs, one-half ounce of the culture being given in milk.

July 27, 1918: The kid shows symptoms of pneumonia 24 days after the first feeding, 7 days after the second feeding. High temperature, abdominal breathing, occasional hard, dry cough; animal appears listless, but appetite is still good. Eyes are somewhat inflamed, coat staring, animal lies down most of the time.

July 28, 1918: Same symptoms as before. Gave three 1/50-grain strychnin tablets as a heart stimulant.

July 30, 1918: Kid refuses all food, grows rapidly worse, and dies at 4.30 p. m., 27 days after the first feeding, 10 days after the second.

July 31, 1918: Post-mortem. Liver shows extensive cirrhosis, but no larvæ are seen. Lungs intensely hemorrhagic and edematous; loaded with larvæ ranging from 0.95 to 1.85 mm. in length, most of the forms measured being well

over 1 mm. Thymus, spleen, and thyroid negative. Larvæ in trachea, pharynx, and esophagus very abundant. Trachea, pharynx, and esophagus show diffuse inflammation of the mucous surfaces. Larvæ numerous in first stomach and in fourth stomach, the latter showing diffuse inflammation. The small intestine contained thousands of young ascarids varying in length from 4.3 to 11.4 mm., averaging 7.9 mm. (29 specimens measured). Presumably these latter were derived from the first feeding and are therefore 27 days old, while the smaller forms in the lungs, trachea, esophagus, and stomach are the result of the second feeding and are therefore 10 days old.

GENERAL SUMMARY.

The embryos in the eggs of *Ascaris suum* or *A. lumbricoides* in the presence of oxygen and moisture may reach full development in 10 days if incubated at a temperature of about 33° C., development proceeding more slowly at lower temperatures and being inhibited by the lack of oxygen or moisture.

The shell of the egg is insoluble in many chemical reagents. Within the shell there is a thin membrane which is highly impermeable and even more resistant to solution than the shell itself. The shell may be dissolved with antiformin, leaving the embryo inclosed in the membrane, in which condition the embryo may continue active for several days.

Hatching of the embryo may occur accidentally outside the body of a host, but occurs normally only in the small intestine. Hatching also occurs if the egg is introduced beneath the skin. The factors that govern the hatching of *Ascaris* eggs are yet to be determined. Martin's conclusions that hatching is caused by alkaline or even neutral solutions acting at body temperature have not been confirmed.

Ascaris eggs in large numbers may be conveniently obtained and developed to the infectious stage for experimental use by removing the eggs from the uteri of female worms and incubating them in a solution of formalin placed in shallow dishes and stirred every few days to insure sufficient aeration.

If *Ascaris* eggs containing fully developed embryos are swallowed by rats, mice, guinea pigs, or rabbits they hatch in the small intestine. Some of the newly hatched larvæ may be eliminated in the feces, but others penetrate the wall of the alimentary tract and apparently aided by the circulation migrate to the liver and lungs; they may also migrate to the spleen and thyroid and under the peritoneum of the abdominal cavity. Most of those entering the liver later migrate to the lungs. In the course of their migrations the larvæ undergo growth and development, reaching five to ten times their original length before leaving the lungs, after which no material change occurs in size or structure. Larvæ that do not reach the lungs ultimately die and become encysted or absorbed by the surrounding tissues. From the lungs the larvæ crawl up the trachea, then down the esophagus through the stomach into the intestine, and

finally pass out of the body in the feces. They may be found in the liver as early as 2 days after infection, in the lungs and trachea as early as 3 days after infection, and in the alimentary tract after their passage through the lungs as early as 6 days after infection. They are common in the lungs a week to 10 days after infection, becoming scarce in the liver as they become numerous in the lungs. Within a little over two weeks after infection all or practically all the larvæ are usually eliminated, but have been found still present and active in the liver, lungs, and alimentary tract as late as 23 days after infection.

In young goats and lambs the larvæ of *Ascaris suum* after migrating through the lungs settle down in the small intestine and undergo development approaching maturity, these animals thus being better adapted as hosts than rats, mice, guinea pigs, and rabbits.

In pigs *Ascaris* larvæ after migrating through the lungs settle down in the small intestines and develop to maturity, and presumably the same cycle occurs in human beings.

Rats and mice play no part in the normal life history of *Ascaris*. The behavior of the larvæ in these animals and in guinea pigs and rabbits may be considered simply an expression of imperfect adaptation of the parasites to existence in these hosts.

In pigs and human beings *Ascaris* may develop to maturity within two and one-half months after infection.

In guinea pigs the larvæ apparently reach a larger average size than in mice in the same length of time, and still larger in rabbits.

Migrating *Ascaris* larvæ produce destructive lesions in the liver and lungs, especially in the latter.

Some larvæ die during their migrations. Dead and degenerated larvæ have been found in the lungs as late as 86 days after infection, and in the liver 296 days after infection.

The invasion of the lungs by *Ascaris* larvæ may result in a serious and sometimes fatal pneumonia, which appears in a week to 10 days after ingestion of the eggs.

Young pigs are more susceptible to *Ascaris* infection than older animals, but may not entirely lose their susceptibility with advancing age.

No evidence has been obtained that one infection with *Ascaris* renders animals less susceptible to later infections.

If properly incubated *Ascaris* eggs are injected beneath the skin they will hatch, and the larvæ will migrate to the lungs, where they may be found a few days after injection of the eggs to have reached the same stage of development as they would if infection had occurred from swallowing the eggs.

The larvæ of *Belascaris marginata* undergo migrations in rats similar to those of *Ascaris suum* and *A. lumbricoides*.

Immature stages of a nematode resembling and probably identical with *Ascaris anoura* have been found in the lungs of a python, indicating that this species, like *Ascaris lumbricoides* and *Belascaris marginata*, migrates through the lungs, reaching, however, a more advanced development before moving into the alimentary tract.

The larvæ of *Hæmonchus contortus* ingested by guinea pigs can be found in the lungs 2 days later, indicating the possibility that this species migrates through the lungs before finally establishing itself in the alimentary tract.

Migration of the larvæ through the lungs is probably a common occurrence in the life cycle of nematodes whose adult stage occurs in the alimentary tract.

Stewart's observations as to the migration of *Ascaris* larvæ through the lungs have been confirmed, but his suggestion that rats and mice act as intermediate hosts is not tenable. No intermediate host is necessary, and human beings and pigs become infected with *Ascaris* as a result of swallowing the eggs of the parasite, and not as a result of swallowing food, water, or other substances that have been contaminated by the feces of rats or mice.

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